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VIRTUAL EXPERIENCE, REAL IMPACT

The influence of virtual reality on memory and behaviour

Anne Cuperus

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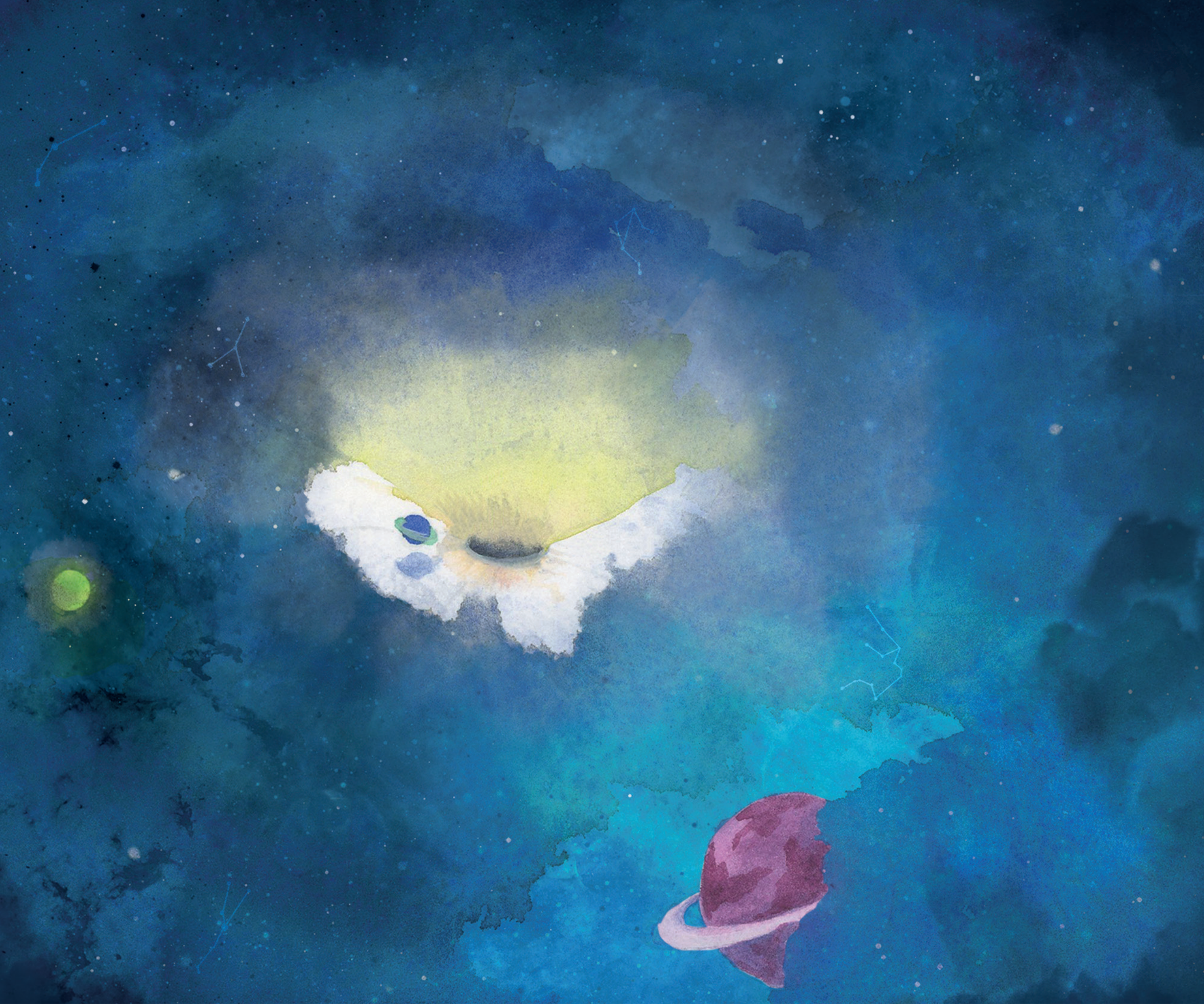


CHAPTER 1

General introduction

In the mid-1990s, an individual with fear of heights, particularly of elevators, entered the Marriott Marquis Convention Hotel in downtown Atlanta. Here, he used the glass elevator to get to the top floor. As one would expect from someone who is afraid of heights, he felt himself getting more and more anxious as he moved up. His palms became sweaty and he felt his chest getting tighter and tighter. Interestingly, however, the elevator was not real, but part of a virtual reality (VR) simulation (Rothbaum et al., 1995). VR simulations can elicit real, psychophysiological fear reactions, as VR is capable of inducing an experience of being personally and physically present in the displayed environment (Wirth et al., 2007). An increased 'sense of presence' is thought to magnify user effects (e.g., the extent to which user responses to virtual stimuli/interactions resemble parallel responses to real-world counterparts) and, in turn, to increase the effectiveness of VR applications (Cummings & Bailenson, 2016). Being able to achieve a strong sense of presence is obviously of great value for the entertainment industry, but has also proven to be useful in the field of healthcare; e.g., the hotel simulation was used to reduce the visitor's fear of heights (Rothbaum et al., 1995). Although a wide variety of VR healthcare applications is already available, however, there are still many untouched opportunities. The aim of this thesis is to increase our understanding of how VR can be applied in healthcare by exploring two novel VR paradigms. Part 1 focusses on the use of VR to model psychological trauma in healthy individuals for research purposes, while part 2 investigates whether VR can be used to affect physical activity by means of a novel kind of perceptual illusion. In this introduction, some important developments in the field of VR and healthcare are first described, as well as where the content of this thesis fits in. Next, the different types of memory and their components are briefly outlined, because the basic mechanisms of human memory are relevant to all of the research presented in this thesis. The fallibility of memory and perception is also discussed here, as well as how this same fallibility provides the basis for both VR paradigms. In the final section, the structure of the thesis is outlined.

VR healthcare applications

Healthcare can benefit from VR in several ways. One promising direction is the use of VR in medical education. For instance, VR simulators can be used to support surgical training. This may improve the technical skills of surgical trainees, such as suturing speed and accuracy (Nagendran, Gurusamy, Aggarwal, Loizidou, & Davidson, 2013). Medical simulators offer immediate, risk-free training opportunities for all sorts of clinical scenarios, including rare procedures that are difficult to practise otherwise (Kunkler, 2006). Similarly, VR may be used to simulate symptoms of mental disorders, so that users can experience what it is like to go through a psychotic episode, for instance. Even without any overt educative elements, this provides a form of experiential learning that may increase users' knowledge of diagnoses and their empathetic understanding towards individuals diagnosed with mental disorders (Formosa, Morrison, Hill, & Stone, 2018).

VR can also be used to facilitate the treatment of medical conditions. The most popular example is, without a doubt, the use of VR in the treatment of anxiety disorders. In VR exposure therapy, patients are exposed to virtual environments that resemble feared real-life situations. This elicits psychophysiological fear reactions, which is a prerequisite for effective exposure treatment (Diemer, Mühlberger, Pauli, & Zwanzger, 2014). VR exposure therapy helped many people overcome specific phobias, such as fear of heights or spiders (for meta-analyses, see e.g., Morina, Ijntema, Meyerbröker, & Emmelkamp, 2015; Parsons & Rizzo, 2008), and research indicates that it can effectively reduce symptoms of post-traumatic stress disorder as well (e.g., Beck, Palyo, Winer, Schwagler, & Ang, 2007; Gerardi, Rothbaum, Ressler, Heekin, & Rizzo, 2008; Rothbaum, Hodges, Ready, Graap, & Alarcon, 2001). Another well-known example is the use of VR as a pain reduction technique in the treatment of acute pain (Garrett et al., 2014), such as pain experienced during wound care by patients with severe burn injuries (Hoffman et al., 2008; Hoffman, Patterson, Carrougher, & Sharar, 2001). Although the exact mechanisms remain unclear, VR is generally hypothesized to be capable of reducing pain by means of distraction (Garrett et al., 2014). VR can provide an engaging environment which draws a lot of attentional resources, leaving less attention available to process pain signals (Hoffman et al., 2001).

VR is also increasingly used to facilitate rehabilitation of several disorders, most notably of stroke. After having a stroke, people often suffer from a variety of symptoms that can cause problems with everyday activities, including an inability to move or feel on one side of the body, problems understanding or speaking, dizziness, or loss of vision to one side. An advantage over traditional therapy approaches is that VR simulations of real-life objects and events give people the opportunity to practise everyday activities that are not or cannot be practised within the hospital environment. This may result in improved limb function and activities of daily living (Laver, George, Thomas, Deutch, & Grotty, 2015). Another rehabilitation example that received a great amount of media coverage involves a group of chronic spinal cord injury paraplegics who were subjected to a gait neurorehabilitation paradigm aimed at restoring locomotion (Donati et al., 2016). This highly innovative approach combined VR training, enriched visual-tactile feedback, and walking with two EEG-controlled robotic actuators, including a custom-designed lower limb exoskeleton capable of delivering tactile feedback to the user. Twelve months of intensive training with this paradigm resulted in unprecedented neurological recovery results in all patients and half of them were upgraded to an incomplete paraplegia classification.

Taken together, the above studies show that VR is playing an important role, or has the potential to do so, in several aspects of healthcare. The paradigms introduced in this thesis are based on the idea that feeling present in a VR environment can lead to highly realistic memories; i.e., a VR experience may be encoded into memory in a manner so similar to a physical world experience that it can even lead to difficulties remembering the source of stored information (Segovia & Bailenson, 2009). Part 1 of the thesis explores the utility of VR to simulate exposure to psychological trauma and subsequent trauma symptoms. This ‘analogue model of psychological trauma’ may be used to study the basic mechanisms underlying trauma symptom development, and to create and test interventions. Part 2 investigates whether a ‘memory-related perceptual illusion’ can be used to affect physical activity. This paradigm is based on how we memorize spatial representations of our environment and may be useful in the field of rehabilitation.

Human memory and perception

It was not until the 1960s that the idea of not one, but multiple systems being involved in memory, became widely adopted among cognitive psychologists. The modal model of memory proposed by Atkinson and Shiffrin (1968), a particularly influential model of the time, describes three stages of memory: sensory memory, short-term memory, and long-term memory. This distinction is still frequently used to explain how our memory works, but it should be noted that some influential researchers object to a modal view (e.g., Nairne, 2002).

The term sensory memory refers to the brief storage of information that enters the senses. Selective attention determines which parts of this information transfer from sensory memory to short-term memory, where it can be stored for a few seconds (without active rehearsal). Short-term memory can be seen as part of working memory; a limited capacity system that not only temporarily stores information but also manipulates it (Baddeley, 2009). The multicomponent model of working memory, proposed by Baddeley and Hitch (1974), is the most influential working memory account to date. Initially, three components were distinguished in this model: the phonological loop which is responsible for maintaining speech-based information, the visuospatial sketchpad which has a similar function for visual information, and the central executive which acts as an attentional control system. A fourth component, the episodic buffer, was later added; a temporary storage system that is capable of integrating information from a variety of sources, including the other components of working memory and long-term memory, under control of the central executive (Baddeley, 2000; for further refinement of the model, see Baddeley & Hitch, in press; Baddeley, 2012). Without such an integration system we would not be able to make sense of the world around us. Our brain uses other sources of information, such as knowledge derived from the past, to actively 'construct' a cognitive understanding of sensory information. As is demonstrated by the study of perceptual illusions, this process makes perception prone to error (Gregory, 1997). Similarly, memory retrieval is not like playing a recording, but should be seen as a 'reconstructive' process (Bartlett, 1932); a memory becomes labile when reactivated and may be influenced by other stimuli, such as suggestive misinformation related to the memory (Loftus, 2005), while in this state. Memory is so fragile that the way questions about a past event are formulated can already alter memory for it. For instance, when asked how fast cars were going in films of automobile accidents, participants reported higher estimates of speed when the question contained the verb 'smashed' than when the same question contained the verbs 'collided', 'bumped', 'contacted', or 'hit' in place of 'smashed' (Loftus & Palmer, 1974). Later studies showed that suggestive misinformation can even lead to the creation of entirely new false memories in people; e.g., by means of a written narrative about one's childhood (Loftus & Pickrell, 1995) or a doctored photograph (Wade, Garry, Read, & Lindsay, 2002).

The downsides to findings like these, such as the challenges they present for the justice system, are evident. However, the malleability of human memory also plays an important role in processing psychological trauma. A traumatic event is described as exposure to actual or threatened death, serious injury, or sexual violence (American Psychiatric Association, 2013). Exposure to such an event may be followed by the persistent re-experiencing of the event (e.g., nightmares), which is considered the hallmark symptom of post-traumatic stress disorder and acute stress disorder (American Psychiatric Association, 2013; James et al., 2016). Just like any other memory, a traumatic memory becomes labile when reactivated and successful trauma interventions interfere with memory when it is in this state (Visser, Lau-Zhu, Henson, & Holmes, 2018; for meta-analyses see e.g., Cusack et al., 2016; Watts et al., 2013). Eye movement desensitization and reprocessing (EMDR; Shapiro, 1989a, 1989b) is such an intervention. One of its key components is a dual-task approach: the patient holds a traumatic memory in mind while simultaneously making voluntary eye movements by tracking the therapist's finger as it moves horizontally across the patient's visual field (Shapiro, 2001). The present state of research points towards an explanation based on working memory as the most solid theory to explain the effects of this dual-task procedure. According to this theory, keeping a memory in mind and making voluntary eye movements both tax the limited capacity of working memory. As a result of this, the memory becomes less vivid and less emotional (Andrade, Kavanagh, & Baddeley, 1997; Gunter & Bodner, 2008; Smeets, Dijs, Pervan, Engelhard, & van den Hout, 2012), and is stored as such into long-term memory (van den Hout & Engelhard, 2012).

The fallibility of human perception can also be used to our benefit. Perceptual illusions are applied in the treatment of several medical conditions. For instance, a mirror visual feedback technique was developed in the 1990s, in an attempt to alleviate phantom limb pain (Ramachandran & Rogers-Ramachandran, 1996; Ramachandran, Rogers-Ramachandran, & Cobb, 1995). It typically involves the use of a mirror across the patient's midline to create the illusion of having two complete limbs. Such 'false visual feedback' may provide relief of phantom limb pain, because of the brain's predilection for prioritizing visual feedback over somatosensory/proprioceptive feedback (Moseley, Gallace, & Spence, 2008). The technique has its limitations, however, because it relies on the presence of an unaffected limb and only allows for symmetric actions. A VR setup is not necessarily subject to such constraints and may thus provide a better alternative (for a review, see Dunn, Yeo, Moghaddampour, Chau & Humbert, 2017); seeing a virtual body from a first-person perspective can induce the illusion of ownership over (parts of) this virtual body (Slater, Spanlang, Sanchez-Vives, & Blanke, 2010). VR can be used to present the user with other types of false visual feedback as well, such as the manipulation of perceived orientation. In a technique called redirected walking, real-world rotations are transformed into increased or decreased rotations in the virtual environment. This allows users to walk through large-scale virtual environments while they physically remain in a small workspace; users can be redirected on a circular arc with a radius of at least 22 m while they believe that they are walking straight (Steinecke, Bruder, Jerald, Frenz, & Lappe, 2010). The same technique can also be used, for instance, to alter the onset of movement-evoked pain in people with neck pain (Harvie et al., 2015).

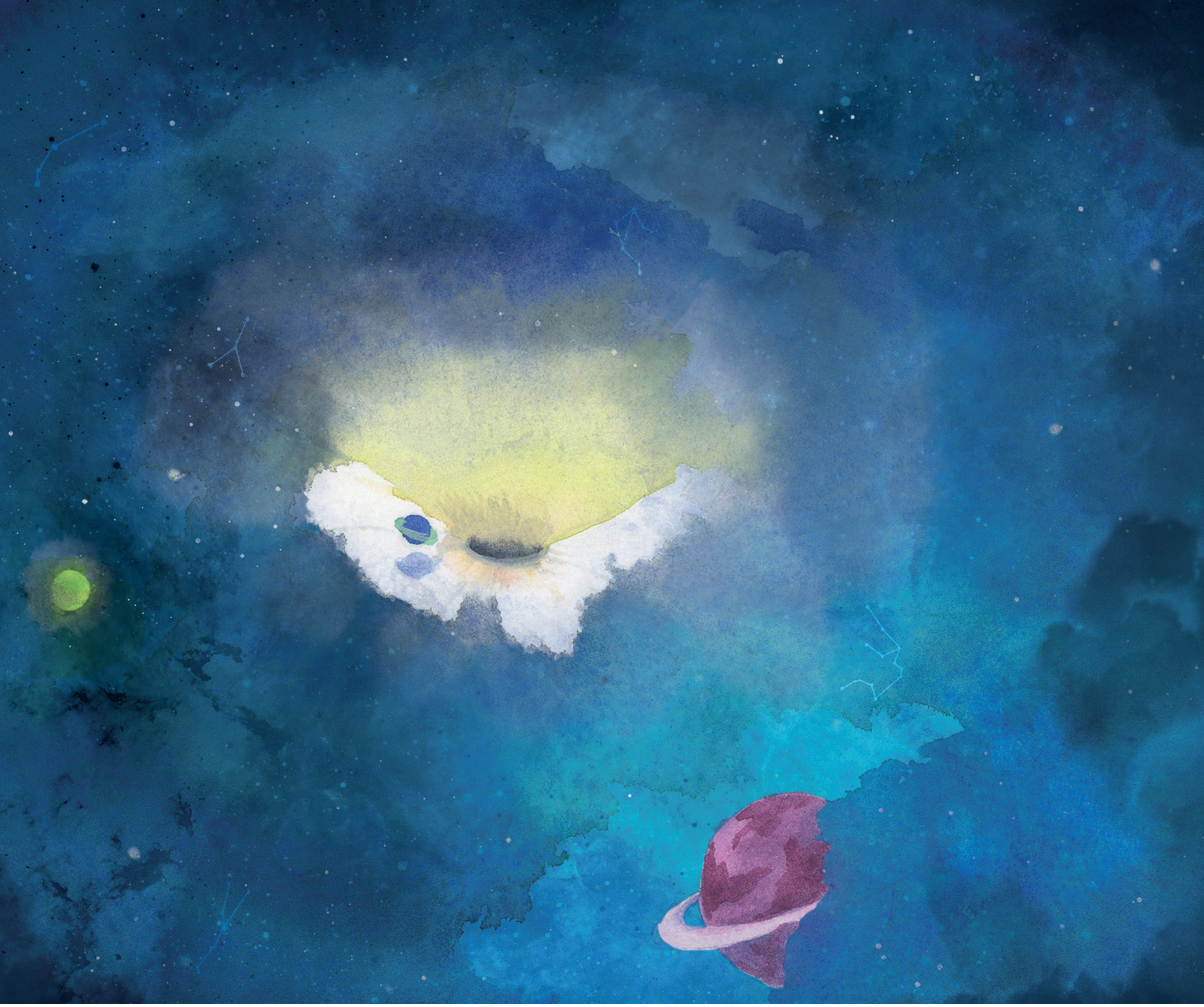
Thesis outline

The general objective of part 1 of this thesis was to validate the utility of a VR paradigm as an experimental analogue of psychological trauma. Experimental analogues can be used to model abnormal processes in order to identify mechanisms of a disorder and to demonstrate proof of concept evidence for clinical developments (James et al., 2016). Clinical studies may be useful in this respect, but a limitation of such studies is that they often rely on retrospective reports of trauma-related reactions many years later. As argued by Candel and Merckelbach (2004), this is problematic because people in general, and patients with trauma symptoms in particular, find it difficult to give accurate descriptions of past emotional states. Moreover, reports of memory for traumatic events often change over time (Engelhard, van den Hout, & McNally, 2008), because individuals may interpret memories differently over time (Engelhard & McNally, 2015; see also Lommen, van der Schoot, & Engelhard, 2014). Experimental analogues are therefore warranted (James et al., 2016). A well-established analogue model of psychological trauma is the trauma film paradigm, which involves showing non-clinical participants unpleasant films under controlled laboratory settings (Horowitz, 1969; Lazarus, 1964). This elicits measurable responses analogous to symptoms experienced during and shortly after viewing a traumatic event in real life, such as increases in negative mood (Clark, Mackay, & Holmes, 2015) and intrusive memories of the film (Holmes & Bourne, 2008; James et al., 2016). However, watching films seems to be a somewhat passive endeavour that lacks active behavioural engagement (Dibbets & Schulte-Ostermann, 2015). VR may provide a better alternative. Like the trauma film paradigm, a benefit of VR over the use of autobiographical memories is that it allows for experimental control. Furthermore, VR can induce a greater sense of presence than watching a film on a two-dimensional screen and it allows interaction with the environment, which may lead to more realistic (Slater, 2009) and more emotional (Riva et al., 2007) responses to portrayed events; i.e., greater user effects. Chapter 2 presents a first step towards validating the VR paradigm. In the study described here, a VR game of the horror genre was used to induce vivid and unpleasant memories in a group of healthy individuals. The effects of a dual-task intervention on self-rated memory vividness and emotionality were then compared with a control condition. However, the question how the effects found in the study relate to the well-established trauma film paradigm was left unanswered, so chapter 3 provides a direct comparison between both paradigms. Outcome measures in the study described here were not limited to vividness and emotionality, but also included trauma-like symptoms such as intrusions following the VR game/film. Finally, chapter 4 presents a study in which the VR paradigm was used to test the effectiveness of an experimental VR-based trauma intervention that consists of a combination of elements from two other interventions: VR exposure therapy and EMDR. Together, the three studies provide a fruitful basis for the use of VR to study psychological trauma, and to create and test interventions.

The main goal of part 2 of this thesis was to use a novel kind of VR-based perceptual illusion to influence users' physical activity. What the previously described false visual feedback examples have in common is that their effects are the direct result of a mismatch between visual feedback and somatosensory/proprioceptive feedback. The focus of this thesis is on a more indirect kind of perceptual illusion that is 'mediated' by memory. In this paradigm, the user is presented with previously experienced, but modified environments and/or events; i.e., their spatial characteristics are altered, without notification to the user. The paradigm is based on the spatial memory framework proposed by Kosslyn (1987), who made a distinction between the representations of coordinate (metric) and categorical spatial relations (e.g., the side of an object in relation to another object). Typically, people are not very accurate in memorizing the precise metric properties of objects and their locations, especially after longer temporal delays. Thus, the manipulation of spatial distance in previously experienced environments and events may go unnoticed when the categorical information of these environments and events matches with memory. First, chapter 5 investigates whether this hypothesis is correct. It describes a study in which participants rated the accuracy of VR replays of their performance on a sports task; accurate representations of actual performance and spatially manipulated ones that made performance seem worse or better. Chapter 6 then explores whether such manipulations of spatial distance in VR (i.e., memory-related perceptual illusions) can also be of clinical relevance. This was tested in a specific clinical population: patients with intermittent claudication; a cramping pain or discomfort in the legs, which occurs during exercise, such as walking, and is relieved with rest (Lane, Ellis, Watson, & Leng, 2014). The main goal of the study described in chapter 6 was to test whether memory-related perceptual illusions can be used to influence treadmill walking distance in this population. However, patients with intermittent claudication typically have several comorbid conditions that may affect memory. Chapter 7 therefore assesses whether the findings of chapter 3 generalize to healthy individuals, so that inferences can be drawn with respect to conditions other than intermittent claudication as well. The three studies provide a framework for the use of memory-related perceptual illusions to affect physical activity in the context of rehabilitation. Finally, chapter 8 summarizes the main findings and conclusions of the thesis.

PART 1

An analogue model of psychological trauma



CHAPTER 2

Degrading emotional memories induced by a virtual reality paradigm

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ABSTRACT

Background and objectives: In eye movement desensitization and reprocessing (EMDR) therapy, a dual-task approach is used: patients make horizontal eye movements while they recall aversive memories. Studies showed that this reduces memory vividness and/or emotionality. A strong explanation is provided by working memory theory, which suggests that other taxing dual-tasks are also effective. Experiment 1 tested whether a visuospatial task which was carried out while participants were blindfolded taxes working memory. Experiment 2 tested whether this task degrades negative memories induced by a virtual reality (VR) paradigm.

Methods: In experiment 1, participants responded to auditory cues with or without simultaneously carrying out the visuospatial task. In experiment 2, participants recalled negative memories induced by a VR paradigm. The experimental group simultaneously carried out the visuospatial task, and a control group merely recalled the memories. Changes in self-rated memory vividness and emotionality were measured.

Results: The slowing down of reaction times due to the visuospatial task indicated that its cognitive load was greater than the load of the eye movements task in previous studies. The task also led to reductions in emotionality (but not vividness) of memories induced by the VR paradigm.

Limitations: Weaknesses are that only males were tested in experiment 1, and the effectiveness of the VR fear/trauma induction was not assessed with ratings of mood or intrusions in experiment 2.

Conclusions: The results suggest that the visuospatial task may be applicable in clinical settings, and the VR paradigm may provide a useful method of inducing negative memories.

Introduction

In the late 1980s, Francine Shapiro introduced a new therapy for post-traumatic stress disorder (PTSD) called eye movement desensitization and reprocessing (EMDR; Shapiro, 1989a, 1989b). One of the key components of the protocol, which is unique to EMDR, is a dual-task approach: the patient holds the traumatic memory in mind while making eye movements by simultaneously tracking the therapist's finger as it moves horizontally across the patient's visual field (Shapiro, 2001). Because EMDR also shares many components with well-established interventions, and there was no strong rationale for using eye movements, sceptics suggested that the eye movements component was unnecessary (see Engelhard, 2012). However, a recent meta-analysis has shown that the addition of eye movements leads to superior results (Lee & Cuijpers, 2013).

Various theories were put forward to explain the effects of eye movements in EMDR. For instance, Christman, Garvey, Propper, and Phaneuf (2003) proposed that horizontal eye movements enhance the ability to retrieve memories of traumatic events due to increased interhemispheric interaction, which may enhance effects of techniques such as exposure. A growing body of research, however, indicates that horizontal eye movements do not improve free recall performance (Matzke et al., 2015). Moreover, Gunter and Bodner (2008) found that vertical eye movements were as effective as horizontal eye movements; both led to an equal decrease in vividness and emotionality of memories. Another theory came from Stickgold (2002), who argued that the repetitive redirecting of attention in EMDR induces a neurobiological state that is similar to that of rapid eye movement (REM) sleep. REM sleep seems to be optimally configured to support the integration of traumatic memories into general semantic networks (Stickgold, 2002, 2008). However, as Pitman et al. (1996) mentioned, there is a lack of phenomenological correspondence between the rhythmic eye movements induced by EMDR and the spontaneous, arrhythmic, non-saccadic eye movements that occur during REM sleep.

Gunter and Bodner (2008) also put another hypothesis to the test derived from working memory (WM) theory. Andrade, Kavanagh, and Baddeley (1997) hypothesized that both making eye movements and keeping a visual image in mind tax the visuospatial sketchpad (VSSP) of WM, which leads to a reduction of the vividness and emotionality of the image. In contrast to this VSSP version of the WM account, Gunter and Bodner (2008) argued that eye movements are effective because they tax the limited capacity of the central executive. These two WM accounts are not incompatible. Research showed that eye movements work better for visual emotional memories and an auditory dual-task works better for auditory memories; yet these modality-specific effects of dual-tasks are superimposed on general effects (Kemps & Tiggemann, 2007; but see Tadmor, McNally, & Engelhard, 2016). The WM account is substantiated by studies that showed that tasks other than eye movements, such as copying the Rey complex figure (Gunter & Bodner, 2008), attentional breathing (van den Hout, Engelhard, Beetsma et al., 2011), and playing the computer game Tetris (Engelhard, van Uijen, & van den Hout, 2010) are effective as well. Although multiple mechanisms may underlie the effects of eye movements in EMDR (Leeds & Korn, 2012), the WM account provides a solid explanation of the effectiveness of other tasks.

The experiments in which effects of 'recall with dual-tasking' are compared with 'recall only' serve as laboratory models of therapy procedures like EMDR. The recalled memories in these experiments are typically aversive and autobiographical (van den Hout & Engelhard, 2012). The use of autobiographical memories may enhance the ecological validity of inferences, but an obvious disadvantage is that the nature of the recalled memories is not under experimental control and may differ substantially between participants. The use of 'trauma films' relating to, for example, traffic accidents (Holmes & Bourne, 2008) may provide an alternative, but a drawback seems to be that watching film clips is a somewhat passive endeavour and lacks active behavioural engagement. Therefore, in the present study, we explored the utility of a VR paradigm in which participants had to navigate through an immersive VR environment by using a button hand controller. This environment was interactive, as it responded to both the participants' viewing directions and their button input.

In recall with dual-tasking vs. recall only studies, the dual-task most often used consists of eye movements (van den Hout & Engelhard, 2012). Here, we explored the utility of using a non-visual task on VR-induced memories instead of eye movements for two reasons. First, given that the recall with dual-task paradigm serves as an experimental model, it would be worthwhile to have a task that could be used not only during memory recall, but also during exposure to visual reminders of the memorized events. Furthermore, adding non-visual tasks to the library of suitable tasks allows patients with limited or no eyesight to benefit from EMDR therapy as well; the commonly used auditory task in EMDR is far less effective than eye movements, as it requires less concentration and no motor operations (van den Hout & Engelhard, 2012; van den Hout, Engelhard, Rijkeboer et al., 2011). We expected that the non-visual task would tax WM, making it useful for the practice of EMDR. Experiment 1 tested whether the task indeed taxes WM. Experiment 2 tested whether the task also reduces vividness and emotionality of emotional memories. We used a VR paradigm to induce negative memories in healthy participants, and compared the influence of the dual-task intervention on the vividness and emotionality of these negative memories to that of recall only.

Experiment 1

Introduction

The non-visual task was a shape sorter task that had to be carried out while being blindfolded. A very similar visuospatial task—shaping plasticine into small cubes and pyramids as fast as possible while the hands are covered with a box—reduced memory vividness and emotionality, as well as intrusion frequency, in a previous study (Krans, Näring, Holmes, & Becker, 2010). We tested whether the shape sorter task taxes WM by means of a reaction time (RT) task in which participants had to respond to auditory cues. The performance on this task alone was compared to the performance on both tasks simultaneously (WM taxing: single-task vs. dual-task). A slowing down of RTs due to dual-task processing indicates the presence and severity of WM taxing by the shape sorter task (Bower & Clapper, 1989; see also van den Hout & Engelhard, 2012). Because haptic processing of peripersonal space comprises several attention-demanding components, such as identifying the nature of objects (Baddeley, 2001; 2012; Postma, Zuidhoek, Noordzij, & Kappers, 2007), we expected dual-task processing to result in higher RTs.

Method

Participants

Twenty male co-workers of a Dutch company (Triple) participated. One participant's data were excluded from the analysis, because he finished the shape sorter task before the RT task was over. The mean age of the remaining 19 participants was 28.8 years (range 22–45; *SD* = 6.5).

Tasks

Random interval repetition (RIR) task. Participants were blindfolded and wearing headphones, and received auditory cues (beeps; 200 Hz) with varying intervals (850 and 1450 ms). They were asked to respond as fast as possible when they heard a beep, by pressing a foot pedal with their right foot. The task contained 20 practise trials followed by 40 experimental trials. RTs below 200 ms were not registered, and responses exceeding 2000 ms were recorded as misses. The RIR task provides a valid measure of WM taxation (Vandierendonck, de Vooght, & van der Goten, 1998; see also van den Hout & Engelhard, 2012).

Shape sorter task. A shape box was positioned in front of the participants. The box (150 × 150 × 150 mm) had holes on four sides, of which only the front- (four holes) and topside (three holes) were used in the experiment. Seven different figures lied in front of the box, and each matched a different hole in the box. Participants were instructed to try to put these figures into the matching holes with their hands. The experimenter stressed that it was important to carefully explore the holes and figures before trying to match them, instead of trying to push the figures through every hole until a match is found. We expected this to lead to greater VSSP taxing, because participants had to identify the nature of the figures and create a conscious image of where objects were.

Procedure

After receiving the task instructions and signing the consent form, participants sat down behind a desk. They were asked to take off their right shoe and place their foot on the foot pedal underneath the desk. When a comfortable position was found, they were blindfolded by a head-mounted display (HMD), so that they would keep their eyes open, and were given headphones to put over their ears. Next, half of the participants (randomly assigned) first carried out the RIR task without the shape sorter task and then carried out both tasks simultaneously. The other half did this in reverse order. After these tasks, participants were debriefed.

Materials

A Lenovo ThinkPad E540 laptop was used. The foot pedal was made out of a Logitech Media Keyboard 600 by the removal of all buttons except the L-button. Participants wore Sennheiser HD 449 headphones and were blindfolded with an unconnected Oculus Rift Development Kit 2 made by Oculus VR. The RIR task was run in OpenSesame version 2.9.5 Hesitant Heisenberg, developed by Mathôt, Schreij, and Theeuwes (2012). The shape sorter was made by Jouéco.

Results

No misses were recorded in the single-task condition. In the dual-task condition, however, participants missed 2.32 out of 40 trials (range 0–7; SD = 2.14) on average, which resulted in a slightly smaller dataset.

Because the data were skewed for the dual-task condition, a Wilcoxon signed-ranks test was run. The RTs of the dual-task condition (M = 594.61; SD = 117.07) were significantly higher than the RTs of the single-task condition (M = 350.24; SD = 35.91), $Z = -3.82$, $p < .01$.

Discussion experiment 1

Several studies found a 100 ms difference for eye movements, compared to a single-task RT task (e.g., van den Hout & Engelhard, 2012; van den Hout, Bartelski, & Engelhard, 2013; van den Hout, Engelhard, Rijkeboer et al., 2011). Although the results have to be interpreted with caution as RTs were measured in a slightly different way in those studies, the shape sorter task seems to be at least as taxing on WM as eye movements.

A limitation of our findings is that only males were included in the experiment. As they generally outperform females on spatial tasks (Voyer, Voyer, & Bryden, 1995), the task might be more taxing on WM for females. Also, participants sometimes missed trials in the dual-task condition, indicating that at those moments it was too difficult for them to focus on both tasks simultaneously. Of course, the shape sorter task is not equally taxing on WM over time as, unlike in case of eye movements, the pace is determined by participants themselves instead of an external stimulus. Furthermore, the shape sorter task comprises multiple different components, such as identifying the nature of objects and constructing a conscious image of where things are within one's reach (see Postma et al., 2007), which are not equally relevant during each phase of the task. This is, however, not a problem per se, as the same applies to games such as Tetris that proved to be useful (e.g., Engelhard et al., 2010).

Experiment 2

Introduction

In this experiment, we tested the effects of the visuospatial task on emotional memories induced by a VR paradigm, by having participants play a VR game that is designed to induce fear. We refer to this VR paradigm as a game, because it was designed to be challenging. It does not involve getting scores or competition, but it is considered to be a challenge to complete the game by reaching the end of the virtual environment (see below) while experiencing fear. We compared the influence of a dual-task intervention (recall + dual-task condition) on the vividness and emotionality of the negative memories to that of recall only (recall no dual-task condition). This was done in a group of healthy participants, as was done in previous experiments (for an overview of studies, see van den Hout & Engelhard, 2012).

The VR paradigm is similar to the trauma film paradigm, which was introduced by Horowitz (1969), and is a well-established method used as an analogue model of psychological trauma (Bourne, Mackay, & Holmes, 2013). Although it is useful, a drawback of the trauma film paradigm is that the participant remains an outsider who does not immerse in the film scenes (Dibbets & Schulte-Ostermann, 2015). Previous research suggests that the use of a VR paradigm should result in stronger emotions, because it induces a 'sense of presence' (Riva et al., 2007). Dibbets and Schulte-Ostermann (2015) recently published the first study in which a VR paradigm was used to induce negative memories. They compared the effectiveness of a short trauma film scene in inducing negative mood and distressful intrusions to that of an interactive VR scene with similar content; a woman being physically assaulted by her lover. The results suggested that the trauma film paradigm was more effective than the VR paradigm.

According to the authors, this may be explained by the experimental setup, because the VR scene was less intense than the film scene. However, another explanation is the lack of an interpersonal relationship between participant and victim (Pfefferbaum, Pfefferbaum, North, & Neas, 2002): the victim was a stranger to participants and the interactive features of the VR scene were limited to the ability to determine one's distance to the event as a passive observer of the scene. We decided to use a VR game in which participants take on a more active role, because distressing events in the game are directed at themselves and are triggered by their actions and decisions. Furthermore, this game contains several randomly generated jump scares. Such unpredictability may increase anxious responses (Grillon et al., 2008).

In the recall + dual-task condition, participants' WM was taxed while focusing on their negative memories of the VR game. We expected that recall + dual-task would lead to greater reductions in memory vividness and emotionality compared to recall no dual-task.

Method

Participants

Participants were recruited via the website proefbunny.nl, a Facebook recruitment page for experiments at Utrecht University, and flyers that were spread at Utrecht University's Faculty of Social Sciences. To be eligible, participants had to be at least 18 years old, and have no known medical history of heart disease or epilepsy. This was made clear through the acquisition text, and participants were asked about their medical history with regard to aforementioned diseases before the start of the experiment. Thirty-four participants (20 male, 14 female; equally distributed across both conditions), most were students at Utrecht University, participated in exchange for remuneration or course credits. Their mean age was 23.5 years (range 18–28; *SD* = 3.4); 22.6 years in recall + dual-task (*SD* = 2.8), and 24.3 years (*SD* = 3.8) in recall no dual-task.

Ethical considerations

The study was approved by the Ethical Committee of the Faculty of Social and Behavioural Sciences of Utrecht University (FETC15-040). Our study was one of the first to use this specific VR paradigm to induce negative memories. More specifically, the emotional response to the VR game we used was largely unpredictable. Therefore, several safety strategies had to be adopted. First, participants were informed about the nature of the VR content (horror) in both the acquisition text and an information letter. Second, participants with a known medical history of heart disease or epilepsy were excluded from participation. Third, we offered participants a short mindfulness session at the end of the experiment. Finally, a therapist was part of the research team and was available for consultation by the participants. This was mentioned in both the informed consent procedure and the debriefing.

Procedure

After reading the information sheet, participants signed the consent form. They were then instructed to put on a HMD and headphones, and to take a button hand controller in their hands. The experimenter then started the VR game Affected, a game that is designed to induce fear. The game starts in a small room with an elevator, which can be freely explored. When participants felt comfortable with the VR environment, they were instructed to select the 'Manor' stage by looking at the corresponding button next to the elevator. Upon entering the elevator, they were taken there. The environment of the manor is generally scary and contains several jump scares, such as a slamming door, a cabinet falling over, and a poltergeist that spawns near you. The goal was to reach the other end of the manor by crossing each section and jump scare once. Upon reaching the end, participants re-appeared in the elevator room following a loading screen.

After finishing the game, participants were asked about the most unpleasant moment of the game. Fig. 1 shows a screenshot of a moment that was frequently selected. A distractor task was then carried out for the removal of gameplay visuals from the VSSP. It was a paper-and-pencil Sudoku puzzle, taken from an online database and ranked level 'easy' (cf. Tadmor et al., 2016). Participants were asked to complete as much of the puzzle as possible within 90 s. This was followed by the memory pre-test, in which participants were asked to recall the moment from the VR game that they considered most unpleasant. They were instructed to visualize this moment and keep an image of it in mind for 10 s, and then rate its vividness and emotionality on two 100 mm visual analogue scales (VAS) that ranged from 0 (not vivid/unpleasant at all) to 100 (extremely vivid/unpleasant; cf. Engelhard, van den Hout, & Smeets, 2011).

Next, participants were asked to wear the HMD while keeping their eyes open; the HMD was turned off and merely served as a blindfold. Participants in the dual-task condition (recall + dual-task) were instructed to retrieve and visualize the selected negative memory while carrying out the shape sorter task from experiment 1. They were asked to do this for 24 s, four times in a row, with 10 s intervals (cf. van den Hout, Muris, Salemink, & Kindt, 2001). The recall no dual-task condition consisted of the same procedure, without the dual-task.

After this, the distractor task continued and the memory post-test was carried out. Apart from the instruction to recall the exact same moment from the pre-test, the post-test was identical to the pre-test. Finally, participants were debriefed and were offered a mindfulness session of approximately 5 min. The duration of the experiment strongly depended on the time it took participants to finish the game, which was generally about 15 min.

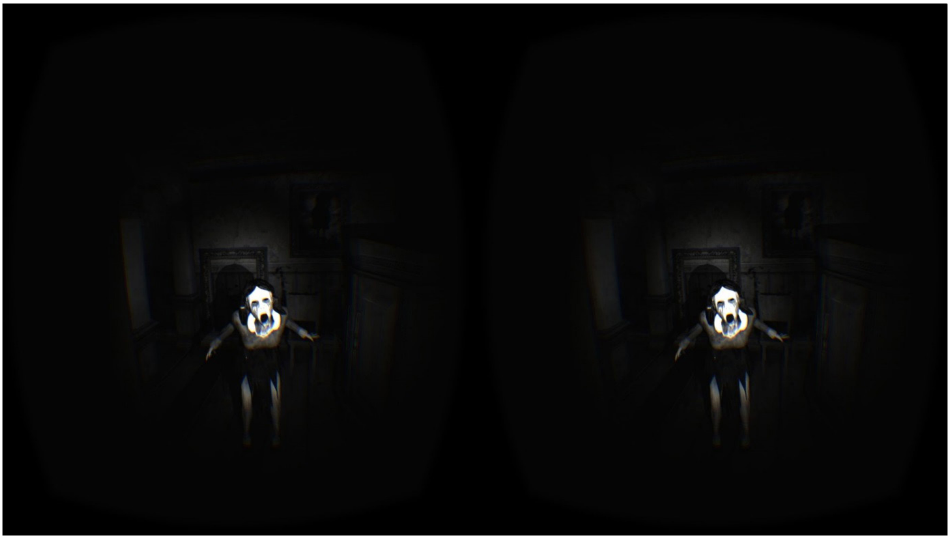


Fig. 1. Screenshot of unpleasant moment in the game.

Materials

We used a PC compiled by VR Powerhouse (model VRP-M1), equipped with a NVIDEA GTX980 graphics card, and an Intel i5-4690 processor. This allowed VR games to run at the suggested framerate (75 FPS) for the HMD we used, namely the Oculus Rift Development Kit 2 made by Oculus VR. The VR game was Affected version 1.55, developed by Fallen Planet Studios (fallenplanetstudios.com). In this game, participants moved through the virtual environment using a Microsoft Xbox 360 controller, while wearing Sennheiser HD 449 headphones. The shape sorter was made by Jouéco and the Sudokus used as distractors were extracted from 1sudoku.net.

Data analyses

Changes in ratings for both measures (memory vividness and emotionality) were analysed by repeated measures ANOVAs with time (pre-test vs. post-test) as within-subjects factor and condition (recall + dual-task vs. recall no dual-task) as between-subjects factor.

Results and discussion experiment 2

Table 1 shows mean scores before and after the two interventions, and Fig. 2 illustrates changes in memory vividness and emotionality.

Table 1. Mean scores (*SD*) on memory vividness and emotionality before (pre-test) and after (post-test) the intervention (recall + dual-task and recall no dual-task).

	Recall + dual-task		Recall no dual-task	
	Vividness	Emotionality	Vividness	Emotionality
Pre-test	75.7 (15.2)	52.4 (29.3)	51.4 (24.8)	41.9 (29.6)
Post-test	69 (14.8)	41.9 (28.1)	52.7 (30.5)	45.3 (33.4)

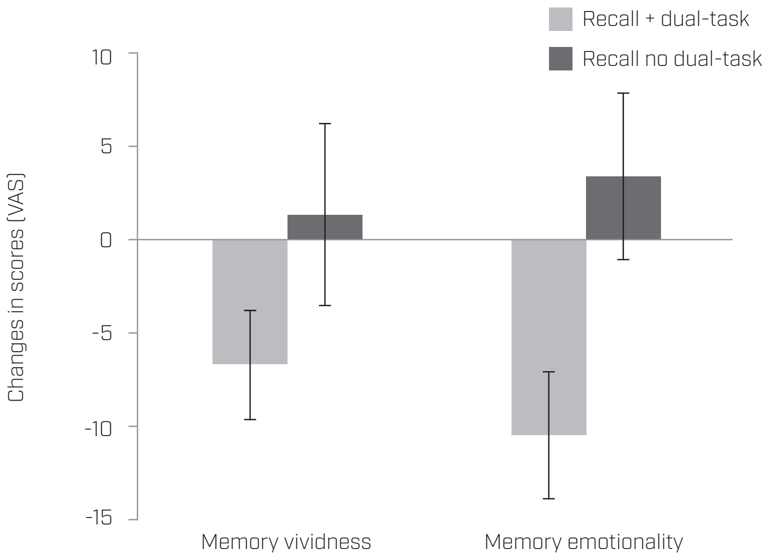


Fig. 2. Changes in memory vividness and emotionality after intervention (recall + dual-task and recall no dual-task). Error bars represent standard errors of difference scores.

With regard to memory vividness, there was no significant main effect for time, $F(1,32) < 1$, but there was a significant main effect for condition, $F(1,32) = 8.20$, $p < .01$, $\eta_p^2 = .20$. However, the crucial time × condition interaction did not reach significance, $F(1,32) = 2.02$, $p = .17$, $\eta_p^2 = .06$.[1]

With regard to memory emotionality, there were no significant main effects for time, $F(1,32) = 1.60$, $p = .22$, $\eta_p^2 = .05$, and condition, $F(1,32) < 1$. Fig. 2 indicates a drop in memory emotionality in the recall + dual-task condition and an increase in the recall no dual-task condition. This was statistically reflected in the crucial time × condition interaction, $F(1,32) = 6.16$, $p < .05$, $\eta_p^2 = .16$. Pair-wise comparisons showed a significant

1 The pre-scores for memory vividness differed between conditions. However, with time defined as pre-test vs. relative decrease, the time × condition interaction did not reach significance either, $F(1,32) < 1$.

decrease in memory emotionality for the recall + dual-task condition, $t(16) = 3.09$, $p < .01$, but no significant increase for the recall no dual-task condition, $t(16) < 1$.

The results were largely consistent with the hypothesis: the dual-task intervention yielded superior results compared to recall only in terms of reductions in memory emotionality. The decrease in the recall + dual-task condition resulted in equal scores as the initial scores for the recall no dual-task condition. However, it should be noted that there were no significant differences in the pre-test emotionality scores between the conditions. It seems that using the VR game was an effective method to induce negative memories.

General discussion

Implications for the WM account

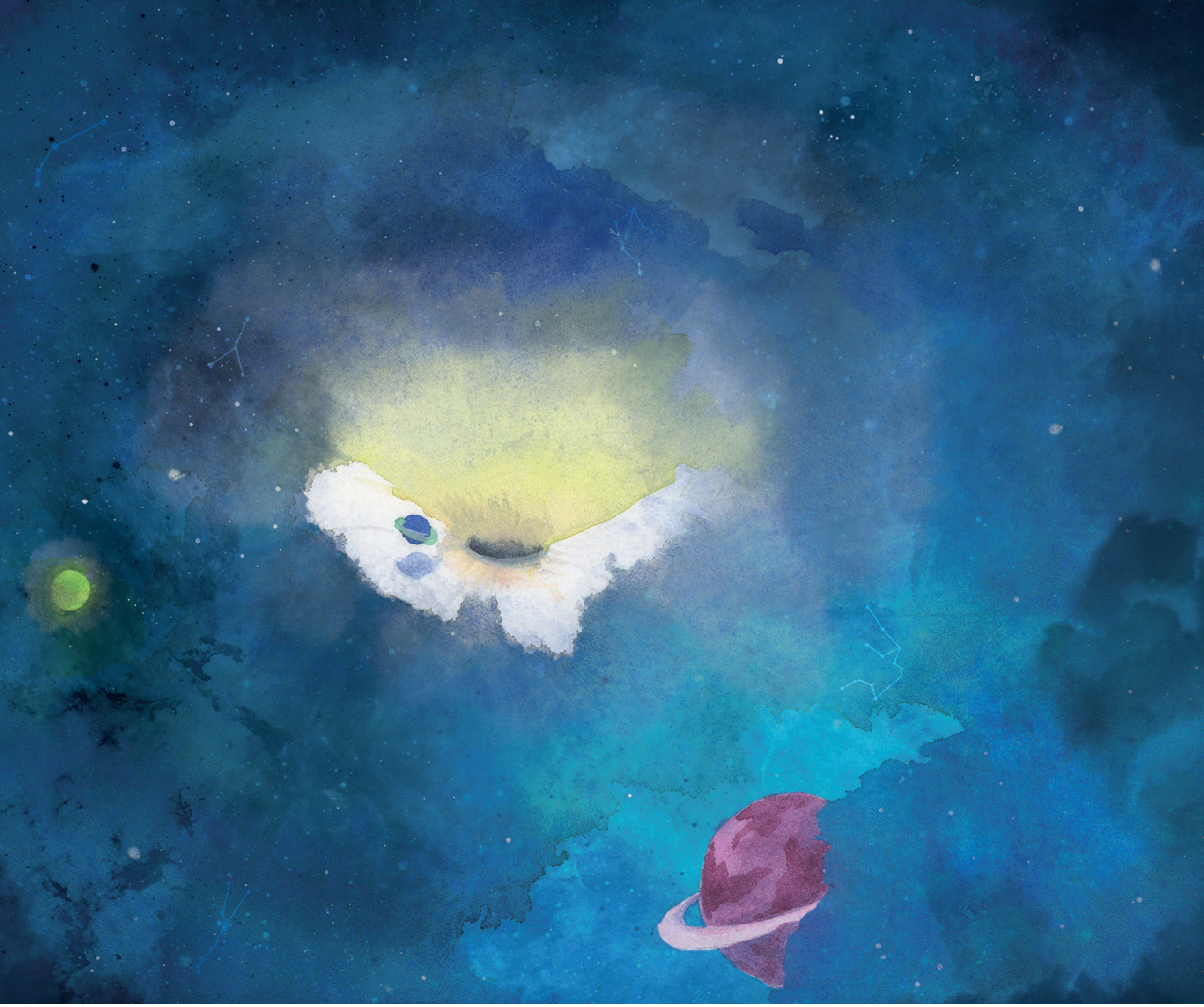
The finding that the emotionality of the recalled memory dropped due to the dual-task intervention supports the WM account of EMDR. However, the intervention did not lead to reductions in memory vividness. It is unclear how this can be explained, but it should be noted that several studies found effects just for memory emotionality (Andrade et al., 1997, experiment 2; Engelhard et al., 2010; Kavanagh, Freese, Andrade, & May, 2001; Schubert, Lee, & Drummond, 2011) or vividness (Andrade et al., 1997, experiment 1; van den Hout, Engelhard, Beetsma et al., 2011, experiment 2; van den Hout, Engelhard, Rijkeboer et al., 2011, experiment 4; Leer, Engelhard, & van Den Hout, 2014; Maxfield, Melnyk, & Hayman, 2008, experiment 1), and not for both. Gunter and Bodner (2008) hypothesized that decreased emotionality is a consequence of decreased vividness. The present results do not support this hypothesis, but do fit nicely within the contrasting view that decreased emotionality results directly from cognitive load modulating emotional responses in the brain; van Dillen, Heslenfeld, and Koole (2009) found that increased task load increases activation in cognitive regions and decreases activity in emotional regions, and that these changes in activity are related. As noted by Kearns and Engelhard (2015), investigating the underlying mechanisms linking dual-tasks to effects on memory emotionality is an important direction for future research. We think it would be interesting to compare the effects on memory of a ‘classic’ dual-task intervention with a dual-task intervention in which recall is visually supported. This can be examined using the VR paradigm from the present study, as (three-dimensional) screenshots from the moments selected as most unpleasant can be recorded and displayed as visual reminders during recall moments. Such an experiment could tell us whether this would prevent a decrease in vividness, and whether this has consequences for emotionality.

Our study and the study by Krans et al. (2010) were not the first to use a visuospatial dual-task intervention that requires haptic processing of peripersonal space. Andrade et al. (1997, experiment 4) compared the effects of a spatial task (tapping a complex boustrophedon pattern on a keypad) on mental images of personal recollections to that of eye movements and a recall only control condition. Vividness and emotionality ratings were given during the interventions. Both dual-task conditions were more effective than the control condition, although the effect of tapping was weaker than that of eye movements. Similarly, van den Hout et al. (2001) compared the effects of a simpler spatial task (rhythmically tapping the table top with index and middle finger together every second) on emotional memories to that of eye movements and a recall only control condition. Only the eye movements condition affected memory vividness and emotionality; negative memories became less negative and positive memories became less positive. This discrepancy is well-accounted for by WM theory. The link between taxing WM and the effect on memory seems to have the form of an inverted U; too little and too much taxing both having little or no effect (Engelhard, van den Hout, & Smeets, 2011). A spatial task may only be effective when it is complex enough.

The use of a VR paradigm to induce negative memories

With the exception of studies using the trauma film paradigm, the effects of dual-task interventions on healthy participants are usually studied using autobiographical memories. One problem of this is that the nature and age of the event underlying the memory differs between participants. Studies have shown that older and stronger memories are less susceptible to modification than younger and weaker ones (see Schwabe, Nader, & Pruessner, 2014). Like the trauma film paradigm, the VR paradigm solves these problems, because it allows control over the nature, intensity and duration of exposure to distressful events. Unlike the trauma film paradigm, however, playing a first-person game while being immersed in a VR environment comes considerably closer to a real-life experience. A small downside that comes with the autobiographical element is that participants are exposed slightly differently from one another due to differences in playstyle (e.g., pace and viewing direction). Still, the VR paradigm seems to combine the best elements of both other methods into one.

The results of the present study suggest that the VR paradigm may provide a useful method of inducing negative memories, as the memories induced by playing the game were strong enough to be affected by the dual-task intervention, but not by recall only. This is, however, only a first step towards validating the utility of the VR paradigm, and based on the present study we cannot draw conclusions regarding its utility as an analogue to real-life trauma. A future study should include pre- and post-game mood ratings (i.e., happy, anxious, depressed and angry; cf. Davies & Clark, 1998a), and test PTSD-like symptoms such as intrusion frequency and distress in the week after (for an elaborate review of studies investigating PTSD-like symptomology, see Holmes & Bourne, 2008). Furthermore, these effects should be directly compared to those of the trauma film paradigm, as was done by Dibbets and Schulte-Ostermann (2015). This will allow us to draw conclusions about the presumed advantages of the VR paradigm.



CHAPTER 3

A virtual reality paradigm as an analogue to real-life trauma: Its effectiveness compared with the trauma film paradigm

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ABSTRACT

Background: The trauma film paradigm (TFP) is a well-established method to study the effects of analogue psychological trauma under controlled laboratory settings. It has been used to examine pre-, peri-, and post-trauma processes, and to create and test interventions. A possible drawback is that watching films is a somewhat passive endeavour that lacks active behavioural engagement. Virtual reality (VR) may provide a better alternative. Like the TFP, VR allows for experimental control. In addition, it can induce a greater sense of presence and allows interaction with the environment, enabling research on action-reaction associations.

Objective: We aimed to validate the utility of a VR paradigm as an experimental model to study psychological trauma by comparing its effectiveness with the TFP.

Method: One group of participants (N = 25) was shown an aversive film, and another group (N = 25) played a VR game. Main outcome measures were intrusion frequency assessed with a 7-day diary and self-rated vividness and emotionality of recalled memories related to the film or VR game.

Results: The results indicate that the film and VR game were equally effective in inducing vivid and intrusive memories. However, self-reported emotional intensity appeared to be higher for memories related to the film than for memories related to the VR game.

Conclusions: Perhaps the film was more effective in inducing emotional memories than the VR game due to its more aversive content. However, the VR game seemed equally effective in inducing vivid and intrusive memories, and merits further exploration in light of ethical considerations (less aversive content) and other presumably beneficial qualities (e.g., inducing a greater sense of presence and allowing interaction with the environment).

Introduction

Post-traumatic stress disorder (PTSD) is a mental disorder that can develop after a person is exposed to a traumatic event. In the 5th Edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5; American Psychiatric Association, 2013), a traumatic event is described as exposure to actual or threatened death, serious injury, or sexual violence. In case of PTSD, this exposure leads to persistent re-experiencing of the traumatic event (e.g., intrusive memories, which are considered to be the hallmark symptom of PTSD; James et al., 2016), persistent avoidance of stimuli associated with the trauma, hyperarousal, and negative alterations in cognitions and mood. In a sample of nearly 3000 American adults, about 89.7% reported exposure to at least one traumatic event in their lifetime and 8.3% had developed PTSD (cf. DSM-5 criteria; Kilpatrick et al., 2013).

A better understanding of the basic mechanisms underlying trauma symptom development is important, because it provides insight into how symptoms can be reduced. Clinical studies may be useful in this respect, but a limitation of such studies is that they often rely on retrospective reports of trauma-related reactions many years later. As argued by Candel and Merckelbach (2004), this is problematic because people in general, and patients with PTSD in particular, find it difficult to give accurate descriptions of past emotional states. Moreover, reports of memory for traumatic events often change over time (Engelhard, van den Hout, & McNally, 2008), because individuals may interpret memories differently over time (Engelhard & McNally, 2015; see also Lommen, van der Schoot, & Engelhard, 2014). Experimental analogues are therefore warranted (James et al., 2016). The trauma film paradigm (TFP) is a well-established alternative method which involves showing nonclinical participants unpleasant films. Unpleasant film viewing as an experimental paradigm was introduced by Lazarus (1964), and was then further refined to study factors related to the development of intrusive thoughts (Horowitz, 1969) and intrusive images (Holmes, Brewin, & Hennessy, 2004) related to the film. The TFP is useful because it offers experimental control and the trauma films typically depict the types of events listed as traumatic in the DSM-5 (events involving actual or threatened death, serious injury, or sexual violence). Moreover, exposure to trauma films elicits measurable responses analogous to symptoms experienced during and shortly after viewing a traumatic event in real life (James et al., 2016), such as increases in negative mood (Clark, Mackay, & Holmes, 2015) and intrusive memories of the film (Holmes & Bourne, 2008; James et al., 2016). The TFP has been used to test pre-, peri-, and post-trauma processes; e.g., mechanisms of memory formation, and vulnerability factors. It has also been used to create and test interventions (for an overview, see Holmes & Bourne, 2008; James et al., 2016).

Dibbets and Schulte-Ostermann (2015) signalled a possible drawback of the TFP: watching films is a somewhat passive endeavour that lacks active behavioural engagement. The participant remains an outsider to the film scenes. Being able to immerse in the film's environment should increase the participant's 'sense of presence', which is commonly described as the feeling of being there, even though you 'know' you are not (Wirth et al., 2007). Virtual reality (VR) may provide a good alternative, because it can induce a greater sense of presence than watching a film on a two-dimensional screen, which may lead to more realistic (Slater, 2009) and more emotional (Riva et al., 2007) responses to portrayed events. Noteworthy in this respect is also a different line of research, in which idiosyncratic autobiographical memories of healthy participants are often used to test the effects of dual-task interventions (van den Hout & Engelhard, 2012). An obvious disadvantage of this approach is that the age of the traumatic events underlying such memories differs between participants. This is problematic because older and stronger memories are less likely to be modified after reactivation than younger and weaker ones (Schwabe, Nader, & Pruessner, 2014). Like the TFP, the VR paradigm solves the problem of experimental control. However, like real-life autobiographical events, VR allows participants to be the protagonist and aversive events to be experienced 'directly'. Moreover, the ability to interact may further increase the sense of presence (Sanchez-Vives & Slater, 2005), and it provides new opportunities to investigate a range of PTSD-predicting factors that cannot be investigated using a 'static' film (e.g., sense of control over the traumatic event).

Recently, Dibbets and Schulte-Ostermann (2015) published the first study aimed at developing a fitting VR analogue to real-life trauma, by comparing the TFP with a VR scene with respect to changes in negative mood and the development of intrusive memories. The VR scene resulted in more immersion, but did not result in stronger changes in negative mood or more intrusions. In fact, intrusion distress was higher after watching the film than after VR. The authors proposed that the VR scene may have been less intense than the film. Cuperus, Laken, van den Hout, and Engelhard (2016) argued that another explanation may be the lack of interactive features of the VR scene, which were limited to the ability to determine one's distance to the event as a passive observer of the scene. They explored the utility of a VR paradigm with more interactive features, in which participants had to navigate through a virtual manor that was designed to induce fear. The aversive events in this environment were directed at the participants themselves and were triggered by their actions and decisions. Some of these events (e.g., a poltergeist spawning nearby) are implausible, but the VR game induced vivid and unpleasant memories, which suggests that it may be a useful method of inducing negative memories. In the present study, we aimed to further validate its use as an experimental model to study psychological trauma by comparing its effects on intrusive memory development and mood with those of the well-established TFP. Vividness and emotionality ratings of recalled memories related to the film or VR game were also compared, and participants filled out an evaluation questionnaire which contained statements about the film or game (e.g., "I felt personally involved").

Bayesian analysis was used to evaluate our hypotheses (Hoijtink, 2012; Mulder, Hoijtink, & de Leeuw, 2012). Although the aversive events in the VR game are likely to be considered scary and/or threatening, they are much less aversive than those of the film we used, which largely consists of acts of rape and physical violence. VR is probably superior in terms of sense of presence, which may compensate for the difference in content. The first hypothesis was therefore that the VR game would elicit an equal amount of intrusions as the film. James et al. (2016) advised researchers to use a film that is sufficiently aversive to model trauma. Therefore, from an ethical point of view, it may be advisable to use the VR game instead of highly aversive film material if both methods are equally effective in terms of intrusion frequency. Nevertheless, given that many studies have found that the TFP is effective (Holmes & Bourne, 2008; James et al., 2016) and that the VR paradigm is relatively novel, the second hypothesis was that the film would elicit more intrusive memories. Finally, because the qualities of VR may overcompensate the less aversive content, we also tested the contrasting third hypothesis that the VR game would elicit more intrusive memories. Following the same rationale, we tested the same three hypotheses with respect to vividness and emotionality of the negative memories induced by both paradigms. We expected pre- to post-film/VR mood changes and the ratings of the four statements of the evaluation questionnaire to follow the pattern to be observed for intrusion frequency.

Method

Participants

Participants were recruited via the website proefbunny.nl, and a Facebook recruitment page for experiments at Utrecht University. To be eligible, participants had to be at least 18 years old. Individuals with a medical history of heart disease or epilepsy, or with psychiatric problems, were excluded. Fifty participants were assigned randomly, but with gender ratio controlled for, to the film condition (nine male, 16 female) or the VR condition (eight male, 17 female). Most of them were students at Utrecht University. They participated in exchange for remuneration or course credits. Their mean age was 22.2 years (range 19–31; *SD* = 3.0); 22.6 years in the film condition (*SD* = 3.5), and 21.7 years (*SD* = 2.4) in the VR condition.

Ethical considerations

The study was approved by the Ethical Committee of the Faculty of Social and Behavioural Sciences of Utrecht University (FETC16-013). We adopted the safety strategies from the study of Cuperus et al. (2016). In the present study, however, participants were not informed about the nature of the VR game and the film in the acquisition text, because we did not want to exclusively attract fans of the horror genre. Instead, prior to the day of the experiment, they were sent the information letter which contained this information, so they still had time to think about participation.

Measures

Neuroticism

The 22 items from the neuroticism scale of the Eysenck Personality Questionnaire (EPQ; Eysenck & Eysenck, 1975) were used to assess neuroticism. Items were rated 'yes' or 'no', which translates to scores of 1 or 0, or vice versa, depending on the question. Higher scores indicate greater neuroticism. For the present study Cronbach's α was .78.

State and trait anxiety

The State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, & Lushene, 1970) was used to assess anxiety. The test is split into the S-Anxiety scale and the T-Anxiety scale, measuring state anxiety (Cronbach's α = .89) and trait anxiety (Cronbach's α = .88) respectively, and each having 20 items. Items of both scales were rated on 4-point scales that ranged from 1 (not at all/almost never) to 4 (extremely/almost always). Higher scores indicate greater anxiety.

Mood

Ratings of mood (happy, anxious, depressed, and angry) were given before and after the film or VR game, on four 100 mm visual analogue scales (VAS) that ranged from 0 (not X at all) to 100 (extremely X; cf. Davies & Clark, 1998b).[1]

Memory vividness and emotionality

Participants were asked to recall the moment from the film or VR game that they considered most unpleasant. They were instructed to visualize this moment and keep an image of it in mind for 10 s, and then rate its vividness and emotionality on two

1 We intended to measure the effect of the film/VR game on state dissociation as well, using the Dissociative State Subscale. However, we only included a post-test and decided not to report the data because of this methodological flaw.

100 mm VAS that ranged from 0 (not vivid/unpleasant at all) to 100 (extremely vivid/unpleasant; cf. Engelhard, van den Hout, & Smeets, 2011).[2]

Evaluation questionnaire

This questionnaire contained four statements about the film or VR game: (1) "I felt personally involved", (2) "The events were unpredictable", (3) "What happened somehow seemed real", and (4) "I was startled by what happened". Participants rated these statements on four 100 mm VAS that ranged from 0 (not X at all) to 100 (extremely X).

Intrusions

Intrusive memories were recorded in a tabular paper-and-pencil intrusion diary for seven days after watching the film/VR (Holmes et al., 2004). Participants noted each intrusion's content and rated whether it was an image, a thought, or a combination of both. For the present study, intrusions are defined as unintended, spontaneously occurring memories that at least contain an image, so mere thoughts were excluded.

Diary compliance

Participants rated the statement "I was often unable (or often forgot) to report my intrusions in the diary" on an 11-point scale that ranged from 0 (totally untrue) to 10 (totally true).

Procedure

After reading the information sheet, participants signed the consent form. They were then shown a neutral film, which was a 1:51 min scene from the movie Coach Carter (Gale, Robbins, Tollin, & Carter, 2005), after which they filled out the EPQ and the STAI, and rated their mood. Depending on random assignment, participants were then shown the trauma film or VR game.

Film condition

The trauma film consisted of four scenes depicting acts of violence and rape from the movie Irréversible (Chioua, Cassel, & Noé, 2002), lasting 6:50 min in total (1 × 140 s, 3 × 90 s; cf. Henckens, Hermans, Pu, Joëls, & Fernández, 2009). Clips from this movie induced intrusive memories in several studies (e.g., Schaich, Watkins, & Ehring, 2013;

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2 For purely exploratory purposes, we also measured heart rate during another 1-min version of this recall task. Also, a 1-min baseline heart rate measurement was established before the film/VR game, so that the effect of recall on heart rate could be derived from difference scores. However, due to interpretation difficulties we decided not to report these data.

Verwoerd, de Jong, & Wessel, 2008). Furthermore, a variety of physiological measures (cortisol level, heart rate, and pupil dilation) confirmed successful stress induction for these particular four scenes (Henckens et al., 2009), and a longer version of the rape scene elicited a higher heart rate, more distress, and more intrusive memories than three other trauma films (Weidmann, Conradi, Gröger, Fehm, & Fydrich, 2009). Participants were instructed to immerse completely into the depicted film scenes, after which the experimenter turned off the light and left the room (cf. Dibbets & Schulte-Ostermann, 2015). The film scenes were projected on a 16.93 × 11.49-inch screen and audio was provided through a headphone (Sennheiser HD 449). Participants started the film by pressing the space bar and were asked to notify the experimenter when it was finished.

VR condition

The VR game was a modified version of Affected version 1.55, developed by Fallen Planet Studios (fallenplanetstudios.com), made to fit the needs of the present study. Unlike in the original version as used by Cuperus et al. (2016), in this modified version participants started in the 'Manor' stage instead of another room where the stage had to be selected first. Furthermore, it contained no random events and only allowed for one route in the manor, so we could be sure that all participants were exposed to the same events.

The environment of the manor is generally scary and contains several jump scares, such as a slamming door, a cabinet falling over, and a poltergeist that spawns nearby. The goal was to reach the other end of the manor by crossing each section and jump scare once. Participants were instructed to notify the experimenter when the end was reached. They were also informed that the experimenter would leave the room after the VR game was started. To prevent that duration of exposure to VR would exceed the length of the trauma film, the experimenter re-entered the room and turned it off after 6:50 min (film duration) if it was not yet finished by then.

Participants moved through the virtual environment using a Microsoft Xbox 360 controller. The visuals were provided through a head-mounted display (Oculus Rift Development Kit 2), and audio was provided through a headphone (Sennheiser HD 449).

After the film or VR game, participants rated the mood scale again. We then used a distractor task to remove film- or VR-related visuals from working memory. It was a paper-and-pencil Sudoku puzzle, taken from an online database and ranked level 'easy' (cf. Tadmor, McNally, & Engelhard, 2016). Participants were asked to complete as much of the puzzle as possible within 90 s. Afterwards, they recalled the moment from the film or VR game that they considered most unpleasant and rated the vividness and emotionality of this memory. Finally, they filled out the evaluation questionnaire and were given the intrusion diary. The experimenter guided them through the written instructions that were included with the diary to make sure that these were clear to them.

Participants returned to the laboratory one week later to hand over the diary and discuss the reported intrusions with the experimenter. They also rated diary compliance, after which they were debriefed and offered a short mindfulness session of approximately 5 min.

Data analyses

Before analysing the data, an analysis plan was formulated. Because neuroticism is related to PTSD symptoms (e.g., Engelhard, van den Hout, & Lommen, 2009; van den Hout & Engelhard, 2004), it was included as a covariate in the analyses. As a result, the hypotheses concern the conditional means. The anxiety variables were added as descriptive statistics. We formulated our expectations regarding the three key variables, intrusion frequency, memory vividness, and memory emotionality, in hypotheses:

H1: $\mu_{film} = \mu_{VR}$
H2: $\mu_{film} > \mu_{VR}$
H3: $\mu_{film} < \mu_{VR}$

The first hypothesis states that the two conditions have equal means on the variable of interest. The second hypothesis specifies that the mean of the relevant variable in the film condition is higher than the mean in the VR condition. The third hypothesis states that the mean in the film condition is lower than in the VR condition. Together, H1, H2, and H3 form all possibilities of equality and inequality between the two means.

A frequentist analysis cannot quantify the relative evidence for a set of null (H1) and inequality constrained (H2 and H3) hypotheses (Wagenmakers, 2007). This is possible using Bayes factors and posterior probabilities. The Bayes factor BF_{12} expresses the support for H1 relative to H2. For example, if $BF_{12} = 1$, both hypotheses are equally supported by the data, if $BF_{12} = 3$, H1 is three times more supported by the data than H2, and if $BF_{12} = .25$, H2 is four times more supported than H1. Some guidelines for interpretation have been proposed by Kass and Raftery (1995), suggesting that a Bayes factor of 3 (or .33) indicates 'substantial' evidence, and a Bayes factor of 10 (or .10) indicates 'strong' evidence. However, we like to emphasize that these are merely guidelines and that, for instance, Bayes factors of 2.8 or 3.1 express rather similar evidence.

The Bayes factors can be used to update prior probabilities of the hypotheses into posterior probabilities that can be used to easily evaluate the relative support for more than two hypotheses given the observed data (Hoijtink, 2012, p. 53). In the present study, we assumed that a priori each of the hypotheses is equally likely; i.e., the prior probabilities are equal for each hypothesis considered.

Bayes factors were computed in BIEMS (Mulder et al., 2012). In order to compute a Bayes factor, a prior distribution for the parameters of the statistical model needs to be specified under each hypothesis. BIEMS computes a suitable (conjugate) prior distribution using a minimal training sample from the data (Mulder et al., 2012). Thus, the prior distribution is based on the data and does not incorporate additional prior information. This results in a so-called default Bayes factor.

Eight variables (the mood and questionnaire variables) were selected for further exploratory analyses. In these analyses, the same set of hypotheses was considered as in the analyses of the key variables (H1, H2, and H3).

For intrusion frequency, one score deviated more than three standard deviations from the mean. Before analysing the data, this score was changed to one unit larger than the next most extreme score in the distribution (Tabachnick & Fidell, 1996).

Results

Baseline variables

Table 1 presents the means and standard deviations for the baseline variables, key variables, and exploratory variables. Both state and trait anxiety were comparable between the two randomized groups. However, we found that despite random assignment the VR group, on average, scored higher on neuroticism.

Main analyses

Table 2 depicts the Bayes factors and posterior probabilities for H1, H2, and H3 for each of the key variables. The preferred hypothesis differs per variable of interest. With respect to intrusion frequency, the best hypothesis is H1, which states that the VR game would elicit an equal amount of intrusions as the film. With respect to memory vividness it seems that, although H1 has more than half of the posterior probability, H2 also has substantial probability and cannot be easily ruled out. Thus, either memory vividness was equal for both conditions or it was higher for the film condition. However, for memory emotionality the best hypothesis is H2, which states that memory emotionality would be higher in the film condition than in the VR condition.[3]

3 The analyses were also executed without neuroticism as a covariate, because the small sample can cause bias in the conditional means. The results were similar, with the exception that none of the hypotheses were clearly preferred for intrusion frequency.

Table 1. Mean scores (*SD*) for the baseline variables, key variables, and exploratory variables.

Variable	Film	VR
Baseline variables		
Neuroticism	4.56 (3.07)	6.80 (4.37)
State anxiety	34.68 (8.29)	35.24 (7.33)
Trait anxiety	33.12 (8.94)	32.44 (5.41)
Key variables		
Intrusion frequency	3.60 (3.83)	3.48 (3.97)
Memory vividness	67.60 (18.20)	62.72 (22.93)
Memory emotionality	69.48 (21.55)	51.08 (25.40)
Exploratory variables		
Happy (post - pre)	-13.92 (18.38)	-17.48 (12.07)
Anxious (post - pre)	11.24 (19.65)	28.80 (21.01)
Depressed (post - pre)	12.36 (16.91)	11.20 (17.84)
Angry (post - pre)	17.12 (19.46)	2.48 (12.37)
Personal involvement	45.84 (31.39)	63.52 (18.87)
Unpredictability	38.40 (23.18)	55.08 (19.24)
Realism	55.52 (26.91)	60.52 (19.06)
Startle	63.08 (24.62)	72.00 (20.12)

Table 2. Bayes factors and posterior probabilities for key variables; H1, H2 and H3 (controlling for neuroticism; EPQ).

Variable	BF_{12}	BF_{13}	BF_{23}	PP H1	PP H2	PP H3
Intrusion frequency	3.58	5.32	1.48	.681	.190	.128
Memory vividness	1.63	8.36	5.13	.577	.354	.069
Memory emotionality	.06	6.22	102.33	.056	.921	.009

Exploratory variables

Table 3 presents the Bayes factors and posterior probabilities for H1, H2, and H3 for all exploratory variables. It shows that there is no clear trend over the variables. For the mood variables, it seems most likely that participants in the film condition had a larger increase in anger than in the VR condition (H2 was supported the most). The increase in anxiety was most likely larger in the VR condition than in the film condition (H3 was supported the most). For the variables 'happy' and 'depressed' it appears that we cannot easily choose the best hypothesis.

Table 3. Bayes factors and posterior probabilities for exploratory variables; H1, H2 and H3 (controlling for neuroticism; EPQ).

Variable	BF_{12}	BF_{13}	BF_{23}	PP H1	PP H2	PP H3
Happy[a]	1.14	3.72	3.26	.467	.408	.125
Anxious	10.00	.05	< .01	.048	.005	.948
Depressed	2.18	2.46	1.13	.536	.246	.218
Angry	.04	8.00	199.00	.038	.957	.005
Personal involvement	6.57	.24	.04	.186	.028	.785
Unpredictability	15.00	.08	.01	.070	.005	.925
Realism	3.35	1.53	.46	.512	.153	.335
Startle	5.00	.59	.12	.347	.069	.584

[a] Higher scores indicate less reduction of happiness ratings.

In the second set of exploratory variables, we found that for personal involvement and unpredictability, both H1 and H2 are unlikely hypotheses relative to H3, indicating that it is most likely that the VR game was more personally involving and unpredictable than the film. Additionally, for the variables ‘realism’ and ‘startle’, H1 and H3 have more weight than H2, but it is not clear which hypothesis is most supported. Thus, it is inconclusive whether the film and VR game were equally realistic and startling (H1) or whether VR was more realistic and startling (H3).[4]

Discussion

The TFP is a well-established method to study the effects of analogue psychological trauma under controlled laboratory settings (for an overview, see Holmes & Bourne, 2008; James et al., 2016). However, because watching films is a somewhat passive endeavour that lacks active behavioural engagement, VR may provide a better alternative (Dibbets & Schulte-Ostermann, 2015). In the present study, we aimed to further validate the VR paradigm used by Cuperus et al. (2016) as an experimental model to study psychological trauma by comparing its effectiveness with the TFP.

The results indicate that the film and VR game were equally effective in inducing vivid and intrusive memories. This is noteworthy, because we used a highly aversive film (Irréversible), depicting physical and sexual violence. As argued by James et al. (2016), in selecting a film, it is not necessarily the aim to find the most aversive film that an ethical committee will allow. They advised researchers to aim to find a film

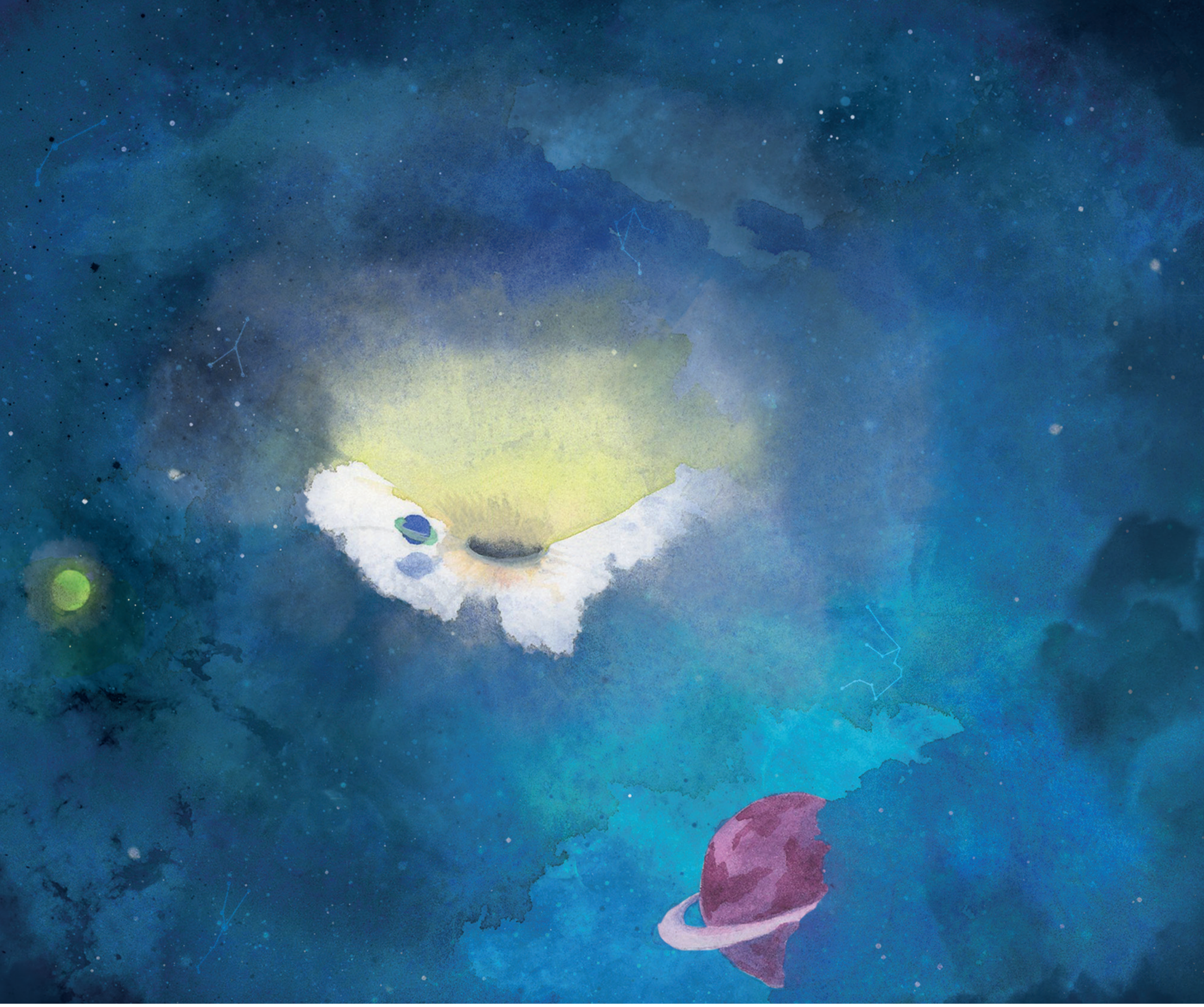
4 The exploratory analyses were also executed without neuroticism as a covariate, because the small sample can cause bias in the conditional means. The results were similar.

that is sufficiently aversive to model trauma. From an ethical point of view, it may be advisable to use the VR game instead of the clips from Irréversible to generate intrusive and vivid memories. This way, participants do not have to be exposed to highly aversive film material. However, watching the film did result in memories of higher emotional valence. In light of ethical considerations and the presumably beneficial qualities of VR (e.g., inducing a greater sense of presence and allowing interaction with the environment), using the VR game could be preferable and at least is worth further exploration.

With respect to the exploratory variables, the results were mixed. Participants in the film condition seemed to show a greater increase in anger than participants in the VR condition, which is likely the result of the morally objectionable content in the film. However, it appears that participants in the VR condition showed a greater increase in anxiety, which may be caused by the fact that the VR game was specifically designed to induce fear. Another possibility may be that the film elicited a wider variety in emotional responses; anxiety and anger, but also horror and disgust (Hagenaars, Brewin, van Minnen, Holmes, & Hoogduin, 2010), whereas the VR game was specifically adequate in eliciting anxiety.

The results also indicated that the VR game was considered more personally involving and unpredictable. Speculatively, the game was considered more involving because it contained events that were directed at participants themselves. The higher unpredictability ratings in the VR condition may be caused by jump scares that are designed to be unpredictable. Note that intrusion frequency for VR and film seemed similar despite these differences, which may suggest that personal involvement and unpredictability are not relevant for intrusion development. However, theoretical models assume otherwise (e.g., Foa, Zinbarg, & Rothbaum, 1992). The influence of these factors is therefore more likely outweighed by the highly aversive content of the film compared to the VR content. For the remaining exploratory variables, the data appears insufficient to express a preference for a certain hypothesis.

One could argue that it is worth exploring more complex and/or aversive VR games, although, from an ethical point of view, we can consider it a strength of our game that it was not extremely aversive; i.e., it may be aversive enough to study the development of intrusive, vivid, unpleasant memories. A direction for future research is to replicate this study with groups that have similar neuroticism scores. It would also be interesting to compare the VR game with a two-dimensional version of the same game. This would provide some insight into the link between sense of presence and PTSD symptoms, and into how far the presumed greater sense of presence is accountable for the results of the present study, as opposed to the difference in content. Alternatively, a presence measure such as the ITC-Sense of Presence Inventory (Lessiter, Freeman, Keogh, & Davidoff, 2001) could be integrated in the design of the present study.



CHAPTER 4

Dual-tasking during recall of negative memories or during visual perception of images: Effects on vividness and emotionality

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ABSTRACT

Background and Objectives: Several treatments are effective in reducing symptoms of post-traumatic stress disorder. We tested the effectiveness of an experimental intervention that consists of elements from two of these: virtual reality (VR) exposure therapy and eye movement desensitization and reprocessing (EMDR). The latter is characterized by a dual-task approach: the patient holds a traumatic memory in mind while simultaneously making voluntary eye movements, resulting in reduced vividness and emotionality of the traumatic memory. If the experimental intervention is effective, it could provide a useful approach for highly avoidant individuals.

Methods: Participants recalled negative memories induced by a VR paradigm. The experimental group viewed VR screenshots that represented these negative memories while carrying out a dual-task. One control group recalled negative memories while carrying out the same dual-task (a standard dual-task condition) and another merely viewed the VR screenshots. Pre-to-post changes in self-rated memory vividness/ emotionality were measured.

Results: The results indicate that viewing a screenshot only was outperformed by both dual-task interventions in terms of reductions in vividness/emotionality. Furthermore, the dual-task interventions had a comparable impact on vividness, but the screenshot variant led to greater decreases in emotionality.

Limitations: Changes in memory vividness/emotionality were only assessed shortly after the interventions and no measures of avoidance behaviour were included in the study.

Conclusions: Looking at an image in VR that represents a memory while carrying out a dual-task may be at least as effective as recalling the memory during the dual-task. Interestingly, visually supporting a negative memory does not seem to prevent memory degrading by dual-tasking.

Introduction

Exposure to actual or threatened death, serious injury, or sexual violence may lead to the development of post-traumatic stress disorder (PTSD). Symptoms include the persistent re-experiencing of the traumatic event, persistent avoidance of stimuli associated with the trauma, hyperarousal, and negative alterations in cognitions and mood (American Psychiatric Association, 2013). There are several treatments that are effective in reducing these symptoms (for meta-analyses see e.g., Cusack et al., 2016; Watts et al., 2013). In the present study we aimed to test the effectiveness of an experimental intervention that consists of elements from two of these treatments: virtual reality exposure therapy (VRET) and eye movement desensitization and reprocessing (EMDR). This was done using a lab model of these interventions in a group of healthy participants, as has been done in previous studies (see van den Hout & Engelhard, 2012).

Exposure therapy involves exposing patients with anxiety conditions to fear-eliciting stimuli in order to decrease their threat expectancy, fear, and avoidance behaviour. VRET is an increasingly common alternative to in vivo and in vitro exposure, in which exposure takes place in virtual environments that resemble feared real-life situations. Several meta-analyses showed that it is an efficacious method of treating anxiety disorders (Morina, Ijntema, Meyerbröker, & Emmelkamp, 2015; Opriş et al., 2012; Parsons & Rizzo, 2008; Powers & Emmelkamp, 2008). Although most research involves effects of VRET in the context of specific phobias, research indicates that the use of virtual environments can effectively reduce PTSD symptoms as well (e.g., Beck, Palyo, Winer, Schwagler, & Ang, 2007; Gerardi, Rothbaum, Ressler, Heekin, & Rizzo, 2008; Rothbaum, Hodges, Ready, Graap, & Alarcon, 2001). VRET might be an interesting alternative in the context of PTSD treatment, because it allows for control over trauma-related exposure stimuli in a safe environment. Moreover, unlike in vivo exposure, it potentially allows the user to visually re-experience an entire traumatic event.

Unlike exposure therapy, EMDR was specifically introduced as a treatment for PTSD (Shapiro, 1989b). One of its key components is a dual-task approach: the patient holds a traumatic memory in mind while simultaneously making voluntary eye movements by tracking the therapist's finger as it moves horizontally across the patient's visual field (Shapiro, 2001). Several theories have been proposed to explain the effects of this eye movement component, but the present state of research points towards an explanation based on working memory (WM) as the most solid theory. According to this theory, keeping a memory in mind and making voluntary eye movements both tax the limited capacity of WM. As a result of this, the memory becomes less vivid and less emotional (Andrade, Kavanagh, & Baddeley, 1997; Gunter & Bodner, 2008; Smeets, Dijs, Pervan, Engelhard, & van den Hout, 2012), and is stored as such into long-term memory (van den Hout & Engelhard, 2012). This implies that keeping a memory in mind while carrying out another task that taxes working memory should also decrease memory vividness and emotionality. Indeed, studies showed that tasks such as copying the Rey complex figure (Gunter & Bodner, 2008), mental arithmetic (van den Hout et al., 2010), and playing the computer game Tetris (Engelhard, van Uijen, & van den Hout, 2010) are effective as well. In contrast, passive tasks, such as listening to tones, are barely taxing and are less effective (van den Hout et al., 2012). We aimed to investigate whether a dual-task intervention in which the recall element is replaced by a VRET element can reduce vividness and emotionality too. That is, instead of thinking of a memory, individuals look at an image in virtual reality (VR) that represents a memory while carrying out the dual-task. If this approach is effective, it could be clinically useful when patients show signs of avoidance behaviour with respect to their traumatic memories during therapy. In those cases, (visual) retrieval cues might be particularly important for an intervention to take effect, because memories are only susceptible to updating when (re)activated (see Visser, Lau-Zhu, Henson, & Holmes, 2018).

In order to test this idea, we induced negative memories in a group of healthy participants by letting them play a VR game of the horror genre (cf. Cuperus, Klaassen, Hagenaars, & Engelhard, 2017; Cuperus, Laken, van den Hout, & Engelhard, 2016). Like the well-established 'trauma film paradigm' (for a meta-analysis, see James et al., 2016), a benefit of this VR paradigm over the use of autobiographical memories is that it allows for experimental control. Furthermore, compared to the trauma film paradigm, VR can induce a greater 'sense of presence' and allows interaction with the environment (for a comparison of both paradigms, see Cuperus et al., 2017). An obvious downside of both paradigms, however, is that personal relevance is still limited compared to actual events in which one's actions may have important consequences. In the present study, three-dimensional screenshots of participants' VR experience were recorded while they played the game (from participants' point of view). After playing, participants viewed the images of the gameplay moments that they found the most unpleasant, while they carried out a non-visual dual-task. This 'shape sorter' task consisted of putting wooden figures into matching holes in a box without visual feedback (Cuperus et al., 2016). We compared the effects of the experimental screenshot + dual-task condition with two control conditions: a standard dual-task condition in which participants recalled the negative memories while carrying out the shape sorter task (recall + dual-task) and a condition in which participants merely viewed the VR screenshots (screenshot only). Before and after the intervention, participants recalled the most unpleasant memory of the VR game and rated how vivid and unpleasant it was. The dependent variables were the changes over time in vividness and emotionality of the targeted gameplay memories.

We tested three competing hypotheses. The first hypothesis, based on WM theory, was that both dual-task interventions would be more effective than the screenshot only intervention. We did not expect effects of habituation in any of the interventions, because the exposure periods were short (cf. Engelhard, van den Hout, Dek et al., 2011). However, there is substantial overlap in neural activation during visual imagery and perception (Ganis, Thompson, & Kosslyn, 2004; Holmes & Mathews, 2010). One may therefore argue that a VR image that represents a negative memory serves as a strong retrieval cue. Therefore, the second hypothesis was that the screenshot + dual-task intervention would be more effective than recall + dual-task. Alternatively, viewing the VR image may prevent the mental image from becoming less vivid and emotional. A previous study suggests that listening to an audio recording of a negative event may negate the blurring effects of the dual-task (Kearns & Engelhard, 2015). Therefore, the third hypothesis was that recall + dual-task would outperform both screenshot interventions. These three hypotheses were evaluated using Bayesian analysis (Hoijtink, 2012; Mulder, Hoijtink, & de Leeuw, 2012):

H1: screenshot + dual-task = recall + dual-task > screenshot only
H2: screenshot + dual-task > recall + dual-task > screenshot only
H3: recall + dual-task > screenshot + dual-task = screenshot only

Methods

Participants

Participants, mostly students, were recruited via social media and flyers. They had to be at least 18 years old to be eligible and individuals with a self-reported medical history of heart disease or epilepsy were excluded. A total of 84 participants (40 male, 44 female) with a mean age of 23.7 years (range 18–35; *SD* = 3.5) were evenly distributed over the different conditions.

Materials

The VR game we used in this study was Affected version 1.55 (Fallen Planet Studios; Southport, United Kingdom). Visuals were provided through an Oculus Rift Development Kit 2 head-mounted display (Oculus VR; Menlo Park, California) and audio was provided through a Sennheiser HD 449 headphone (Sennheiser electronic GmbH & Co. KG; Wedemark, Germany). Participants moved through the game using an Xbox 360 controller (Microsoft; Redmond, Washington). Screenshots were recorded with Fraps 3.5.99 (Beepa Pty Ltd.; Melbourne, Australia). The PC was equipped with an NVIDIA GeForce GTX 980 graphics card (NVIDIA; Santa Clara, California) and an Intel Core i5-

4690 processor (Intel; Santa Clara, California). The shape sorter used in the dual-task conditions was made by Jouéco (Waddinxveen, The Netherlands) and the Sudokus were extracted from 1sudoku.net (level 'easy').

Conditions

Screenshot + dual-task

During the intervention phase, participants in the screenshot + dual-task condition viewed a three-dimensional screenshot of the moment from the VR game that they labelled as most unpleasant after playing it. This screenshot was shown through the head-mounted display for 24 s, four times in a row, with 10 s intervals during which the screen turned black (cf. the procedure of van den Hout, Muris, Salemink, & Kindt, 2001). While focusing on the image, participants carried out the shape sorter task.

Recall + dual-task

The procedure of the recall + dual-task condition was the same as the screenshot + dual-task procedure. Instead of viewing a screenshot while carrying out the shape sorter task, participants were instructed to retrieve and visualize the moment they labelled as the most unpleasant memory during the 24 s periods.

Screenshot only

The screenshot only condition was identical to the screenshot + dual-task condition but did not contain the shape sorter task; participants merely viewed the screenshot they selected.

Procedure

After providing written consent, participants put on the head-mounted display and headphone and received the game controller. The VR game Affected started, as well as the Fraps application that recorded gameplay screenshots with 1 s intervals. The game contains an abandoned old mansion with several jump scares (e.g., a cabinet suddenly falls over and a poltergeist spawns near the participant; see Fig. 1 for screenshots). Participants were instructed to reach the last of a series of rooms using the game controller, without a time limit (cf. Cuperus et al., 2016). The experimenter left the room during the game and re-entered it when participants gave a signal that they finished the game. Participants were then asked to remember and describe the most unpleasant moment of the game. The experimenter wrote down their description. They then carried out a paper-and-pencil Sudoku puzzle with the instruction to complete as much of the puzzle as possible within 90 s. This distractor task was used to make sure that any remaining gameplay visuals were removed from WM (Tadmor, McNally, & Engelhard, 2016). In the screenshot conditions, the experimenter used this time to look up the screenshot that best matched the most unpleasant moment that was described by the participant. Then, in a memory pre-test, participants were instructed to visualize the moment they labelled as most unpleasant and keep an image of it in mind for 10 s. They then rated its vividness and emotionality on two 100 mm visual analogue scales (VAS) that ranged from 0 (not vivid/unpleasant at all) to 100 (extremely vivid/unpleasant; Engelhard, van den Hout, & Smeets, 2011). Next, depending on the condition, participants were subjected to the screenshot + dual-task, recall + dual-task, or screenshot only intervention. They then carried out another Sudoku puzzle for 90 s, followed by a memory post-test that was identical to the pre-test. Finally, participants were debriefed and offered a mindfulness session of approximately 5 min to reduce potential residual stress (cf. Engelhard, van den Hout, Dek et al., 2011).

Fig. 1. Screenshots of the VR game (Affected) that participants played.

Data analyses

Our hypotheses were evaluated using a Bayesian model selection criterion based on the Bayes factor (BF; Kass & Raftery, 1995). The BF is the primary outcome in a Bayesian framework and states the likelihood of one hypothesis relative to another hypothesis. For instance, $BF_{12} = 5$ means that the data are five times more probable under hypothesis 1 than under hypothesis 2. BIEMS is a software program that can be used to evaluate competing hypotheses based on the BF (e.g., Mulder, Hoijtink, & Klugkist, 2010). By default, BIEMS computes a BF for each constrained hypothesis against the same unconstrained hypothesis. A constrained hypothesis is made up of a collection of restrictions that specify the relationships between conditions (e.g., A > B > C or A = B < C), while an unconstrained hypothesis does not specify these relationships and only states that there are means in the hypothesis (i.e., A, B, C). As a result, A BF of 1 means that compared to an unconstrained hypothesis, the constrained hypothesis receives equal support. BF > 1 indicates that the constrained hypothesis outperforms the unconstrained hypothesis and BF < 1 means the opposite. Because the BFs for all constrained hypotheses are determined at the same time and all are relative to the same unconstrained hypothesis, the relative support for one constrained hypothesis over another can be determined simply by dividing the BFs of these hypotheses (Béland, Klugkist, Raîche, & Magis, 2012).

Results

Table 1 shows BFs for each constrained hypothesis, Table 2 shows mean vividness and emotionality scores before and after the three interventions, and Fig. 2 illustrates changes in vividness and emotionality. It shows greater decreases in vividness and emotionality as a result of both dual-task conditions compared to screenshot only. This is reflected in the Bayesian analyses, which show that hypotheses 1 and 2 are more likely than model 3 for both variables. Fig. 2 further shows that screenshot + dual-task yields the greatest decreases, but the difference with recall + dual-task is greater for emotionality than for vividness. This difference is emphasized in the strengths of evidence (i.e., the size of the BF); hypothesis 1 is more likely compared to hypothesis 2 for vividness, while the reverse is true for emotionality.

Table 1. Bayes factors (BF) for vividness and emotionality, for each constrained hypothesis.

Hypothesis		$BF_{vividness}$	$BF_{emotionality}$
1:	screenshot + dual-task = recall + dual-task > screenshot only	6.38	3.37
2:	screenshot + dual-task > recall + dual-task > screenshot only	3.21	5.06
3:	recall + dual-task > screenshot + dual-task = screenshot only	0.03	0.03

Table 2. Mean vividness and emotionality scores (*SD*) before (pre-test) and after (post-test) the interventions.

	Screenshot + dual-task		Recall + dual-task		Screenshot only	
	Vividness	Emotionality	Vividness	Emotionality	Vividness	Emotionality
Pre-test	63.07 (18.17)	54.64 (20.89)	56.93 (14.12)	44.79 (23.75)	60.14 (22.72)	50.46 (23.24)
Post-test	53.07 (25.30)	33.07 (23.62)	47.50 (17.73)	28.39 (16.84)	67.18 (21.45)	44.36 (25.58)

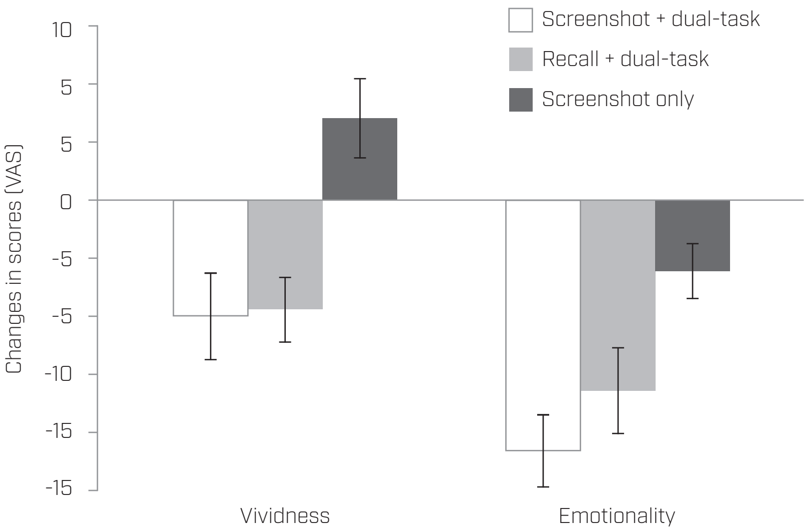


Fig. 2. Changes in vividness and emotionality for each intervention. The error bars represent standard errors of the difference scores.

Discussion

According to WM theory, the voluntary eye movement component of EMDR is effective because keeping a memory in mind and making (endogenously generated) eye movements both tax the limited capacity of WM. As a result of this, the memory becomes less vivid and less emotional (Andrade et al., 1997; Gunter & Bodner, 2008) and is stored as such (van den Hout & Engelhard, 2012). In line with this theory, the results indicate that screenshot only was outperformed by both dual-task interventions in terms of reductions in self-rated memory vividness and emotionality. Self-reports are prone to demand bias, but studies using physiological measures and memory performance measures found similar results (see Leer et al., 2017). The finding adds to the evidence that the VR paradigm may provide a useful method of inducing negative memories (Cuperus et al., 2016, 2017). Furthermore, it seems that the dual-task conditions had the same impact on vividness, but that screenshot + dual-task led to greater decreases in emotionality.

It is unlikely that the difference between the dual-task conditions in terms of reductions in emotionality was caused by effects of habituation due to VR exposure, because periods of exposure were very short (Engelhard, van den Hout, Dek et al., 2011). A more probable explanation for the difference may lie in the finding that the dual-task we used is much more taxing than the eye movements that are typically used in the clinical practice of dual-task desensitization (Cuperus et al., 2016). That is, extremely taxing tasks may prevent the retrieval or maintenance of an image (Engelhard, van den Hout, & Smeets, 2011), which may have led to a slight underperformance of recall + dual-task. In the screenshot + dual-task condition, on the other hand, the image was constantly presented through the VR headset, which likely facilitates memory activation. Thus, whereas the link between taxing WM and the effect on memory vividness and emotionality may have the form of an inverted U for interventions with self-initiated memory recall (i.e., tasks being too taxing or not taxing enough both having little or no effect; Engelhard, van den Hout, & Smeets, 2011), this may not be the case for screenshot + dual-task, where memory recall may be more automatic. Instead, here the link may be linear, meaning that the more WM is taxed by carrying out a dual-task, the greater the effect on vividness and emotionality. Note that it is assumed that presenting a screenshot always captures attention and taxes WM. Such a finding could be useful in a clinical context, so further investigation of this hypothesis is warranted.

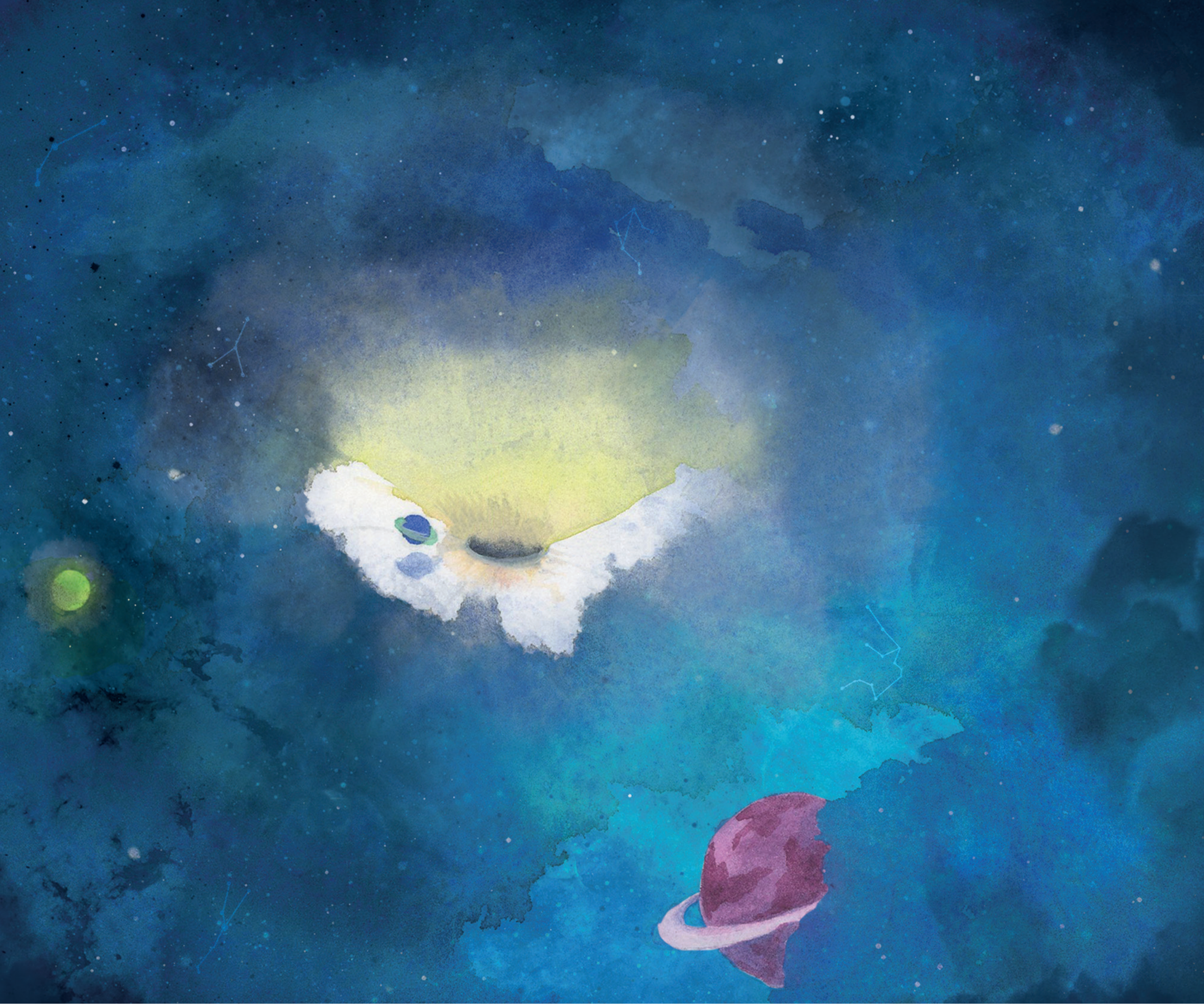
Aside from this possible benefit over recall-based interventions, a screenshot + dual-task approach might be clinically useful when patients show signs of avoidance behaviour with respect to their traumatic memories during therapy. It would be interesting to test whether avoidance moderates the effects of the interventions, and if individuals with strong avoidance tendencies benefit most from screenshot + dual-task. In practice, however, images of a traumatic event are usually not available, let alone three-dimensional VR images. Therefore, future studies should also investigate whether viewing (VR) images that trigger a negative/traumatic memory while carrying out a dual-task yields positive effects as well. This could be done in a group of patients or healthy participants with negative autobiographical memories, by letting them select triggering images (cf. the Virtual Iraq exposure therapy system; Rizzo, Reger, Gahm, Difede, & Rothbaum, 2009).

Conclusions

Taken together, we conclude that looking at an image in VR that represents a memory while carrying out a dual-task may be at least as effective as the recall variant. Interestingly, visually supporting a negative memory does not seem to prevent the beneficial effects of dual-task processing on an emotional memory. Further investigation of the practical utility of this approach is warranted and the idea that it might especially be efficacious for patients that show signs of avoidance behaviour with respect to their traumatic memories during therapy requires further testing.

PART 2

Memory-related perceptual illusions



CHAPTER 5

Virtual reality replays of sports performance: Effects on memory, feeling of competence, and performance

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ABSTRACT

Memory can be altered after receipt of misleading information; this misinformation effect was first studied almost 40 years ago. Later studies showed that suggestive information could even lead to the creation of new false memories in people. Whereas previous research focused primarily on false information about passively observed events, we aimed to investigate whether memory for one's own physical performance can be altered by means of false, manipulated replays of these events in virtual reality, displayed from a first-person viewpoint. We further explored the possibility of using the misinformation effect beneficially, by investigating whether it can affect feeling of competence, as well as subsequent sports performance. Participants (N = 27) took 4 series of shots at a goalpost on a football field. Between these series, they were shown three different types of virtual reality replays of their performance; 1 accurate representation of actual performance and 2 manipulated versions, 1 that made performance seem worse (negative manipulation) and 1 that made performance seem better (positive manipulation). Participants rated their feeling of competence before and after each replay and rated how accurately the replay displayed their real-life shots at the goal. The manipulated replays were considered equally accurate representations of actual performance as the non-manipulated ones. Also, the type of replay manipulation positively correlated with feeling of competence but did not influence sports performance. The present study showed that memory for one's own physical performance can be altered by means of manipulated virtual reality replays and that this can be used beneficially.

Introduction

For quite some time now it has been known that retrieving memories is a reconstructive process (Bartlett, 1932). Unlike a video recording, which is the same when played repeatedly, information retrieval from human memory is susceptible to error. Memory may be altered after receipt of misleading information; the first study on this 'misinformation effect' was conducted almost 40 years ago by Loftus, Miller, and Burns (1978). Studies showed that false details can be planted into memory for both simulated (e.g., a filmed car accident), as well as real-world events (Loftus, 2005). Moreover, the way questions about a past event are formulated can even alter memory for it. For instance, when asked how fast cars were going in films of automobile accidents, participants reported higher estimates of speed when the question contained the verb 'smashed' than when the same question contained the verbs 'collided', 'bumped', 'contacted', or 'hit' in place of 'smashed' (Loftus & Palmer, 1974). Such findings stress the importance of using proper questioning techniques in court testimonies (Powell, 2005).

Later studies showed that suggestive information could even lead to the creation of new false memories in people. False memories were implanted by means of various forms of media, such as a written narrative about one's childhood (Loftus & Pickrell, 1995) or a doctored photograph (Wade, Garry, Read, & Lindsay, 2002). These studies can be framed in terms of varying levels of 'media richness' (Segovia & Bailenson, 2009), which can be described based on four criteria: capacity for immediate feedback, capacity to transmit multiple cues such as graphic symbols or human gestures, language variety, including numbers and natural language, and capacity of the medium to have a personal focus (Daft, Lengel, & Trevino, 1987). According to Segovia and Bailenson (2009), the stronger the false, suggestive information is in terms of media richness, the more likely people are to adopt the information into memory. The personal focus criterion may be especially important in this respect, as self-referent encoding yields superior memory (Symons & Johnson, 1997).

Whereas previous research focused primarily on false information about passively observed events, in the present study we aimed to investigate whether memory for one's own physical performance can be altered by means of false, manipulated replays of these events in virtual reality (VR), displayed from a first-person viewpoint. The inherent characteristics of VR (e.g., user-specific viewpoints and a wide, three-dimensional field of view) provide a great sense of immersion, which makes it a very rich form of media (Segovia & Bailenson, 2009). We therefore expected that watching the manipulated replays would alter memory, so that the manipulated replays would be considered equally accurate representations of actual performance as the non-manipulated ones. In the present study we further explored the possibility of using the misinformation effect beneficially, by investigating whether the manipulated replays can affect feeling of competence, which refers to the concept of 'self-efficacy' as introduced by Bandura (1977); the extent or strength of one's belief in one's own ability to complete tasks and reach goals. If so, such replays could potentially be used for therapeutic purposes, such as prevention or treatment of performance anxiety following bad performance in, for example, a football match. Furthermore, they may affect subsequent sports performance, as an increased feeling of competence should lead to an increase in intrinsic motivation, which in turn is positively correlated with quality of performance (Ryan & Deci, 2000).

Method

Participants

Participants were recruited via coaches of different soccer clubs and through a Facebook advertisement. To be eligible, participants had to be at least 18 years old and have played on a football team at a club for at least one year. Twenty-seven male amateur football players participated and their mean age was 23.2 years (range 18–28; *SD* = 3.00).

Procedure

After reading the information sheet, participants signed the consent form. According to the information sheet, the goal of the experiment was to test the effects of watching VR replays of one's own sports performance on subsequent performance. Participants were first instructed to carry out a physical sport task, in which they had to take 10 shots across the ground at the left goalpost on a football field, from a 16.5 m distance (Fig. 1).

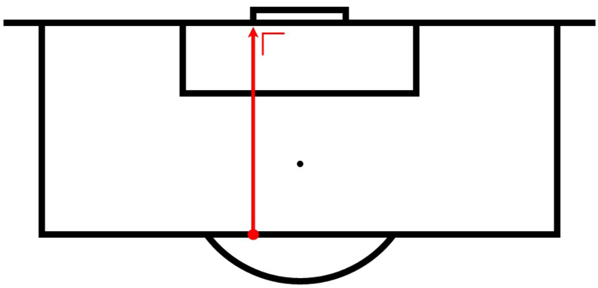


Fig. 1. The resting position of the ball during the sport task in the experiment (red dot).

The experimenter recorded the distance missed with respect to the goalpost, as well as the side of the goalpost along which the ball passed. The distances were read from a tape measure (10 m long), which was rolled out on the goal line. After the sport task, participants were taken to the side of the field. Here, they rated their feeling of competence by indicating how difficult they considered the sport task, and how good they considered themselves in carrying out the task, on two 100 mm visual analogue scales (VAS) that ranged from 0 (very hard/very bad) to 100 (very easy/very good). Meanwhile, the experimenter entered the recorded miss distances and sides of the goalpost into the VR application (a modification of Beyond Sports v0.53; developed by Triple). When the competence test was finished, participants were instructed to put on the head-mounted display (Oculus Rift Development Kit 2), through which the first VR replay of their performance on the sport task was shown for all 10 shots (Fig. 2).

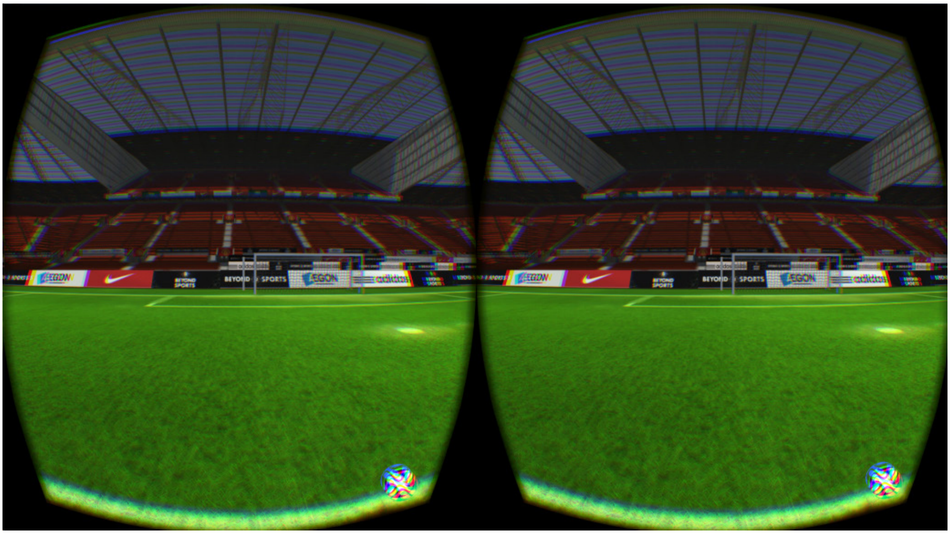


Fig. 2. Monitor display during a VR replay.

The VR replays could either be an accurate representation of the actual performance or a manipulated version thereof. In the manipulations the distance between the ball and the goalpost was adjusted, making the performance seem worse (miss distances multiplied by 1.5; negative manipulation) or better (miss distances multiplied by 0.5; positive manipulation) than the actual performance. The VR application contained no hit detection system, so if in reality the ball hit the goalpost or the net, the replay would show the ball going through it.

After the replay, participants rated their feeling of competence a second time, as well as how accurately the replay displayed their real-life shots at the goal on a single 100 mm VAS that ranged from 0 (very inaccurately) to 100 (very accurately). The sequence from the sport task to the replay accuracy rating was repeated two more times, so that all three types of VR replays were shown. The order in which the replays were offered was counterbalanced among participants. Finally, the sport task was carried out one last time. Afterwards, participants were informed about the actual goal of the experiment, and were told in which order the different types of replays were shown. The total procedure took approximately 40 min.

Data analyses

Scores on all measures (perceived replay accuracy, feeling of competence, and sports performance) were analysed by repeated measures ANOVAs with manipulation type (negative vs. none vs. positive) as a within-subjects factor.

Results

Fig. 3 shows mean scores on perceived replay accuracy, for each type of manipulation. Mauchly's test indicated that the assumption of sphericity was violated ($\chi^2(2) = 6.09$, $p < .05$); therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .82$). The repeated measures ANOVA showed that perceived replay accuracy was significantly influenced by type of manipulation, $F(1.65, 42.76) = 5.52$, $p < .05$, $\eta_p^2 = .18$.

Post-hoc Bonferroni corrected t-tests showed that positive manipulations were rated as significantly more accurate representations of performance than negative manipulations, $p = .03$. Also, a trend showed that non-manipulated replays were rated as more realistic than negative manipulations, $p = .07$.

Fig. 4 illustrates changes (pre vs. post VR replay) in feeling of competence, for each type of manipulation. The repeated measures ANOVA showed that feeling of competence was significantly influenced by type of manipulation, $F(2, 52) = 26.46$, $p < .01$, $\eta_p^2 = .50$.

Post-hoc Bonferroni corrected t-tests showed that the increase in feeling of competence after watching positive manipulations differed significantly from the decrease after watching negative manipulations, $p < .01$. The same conclusion applies to watching non-manipulated replays compared to negative manipulations, $p < .01$. Finally, the increase in feeling of competence after watching positive manipulations was also significantly greater than the increase after seeing non-manipulated replays, $p < .05$.

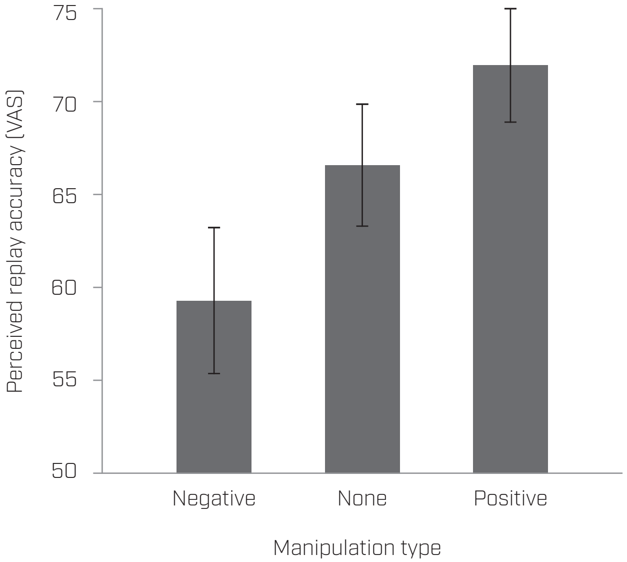


Fig. 3. Mean VAS (0; very inaccurately – 100; very accurately) scores on perceived replay accuracy for manipulated and non-manipulated VR replays. The error bars represent standard errors.

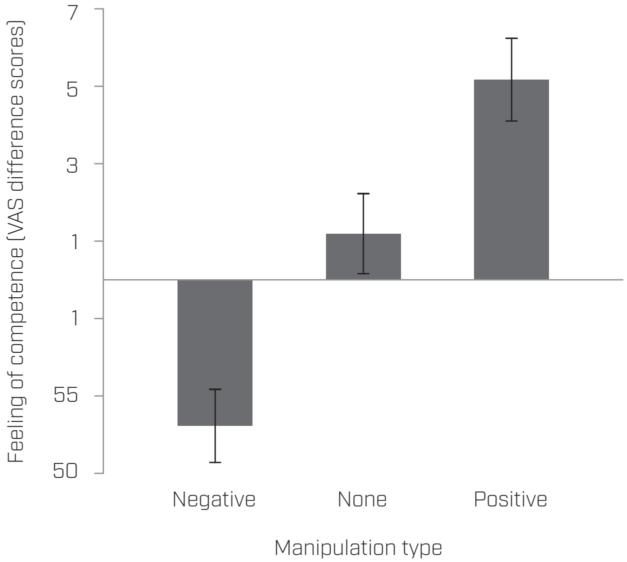


Fig. 4. Mean VAS (0; very hard/very bad – 100; very easy/very good) difference scores on feeling of competence following manipulated and non-manipulated VR replays. The error bars represent standard errors.

Fig. 5 shows sports performance, measured in mean distance missed (cm), for each type of VR replay. Mauchly's test indicated that the assumption of sphericity was violated ($\chi^2(2) = 7.43$, $p < .05$); therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .80$). The repeated measures ANOVA showed that sports performance was not significantly influenced by type of manipulation, $F(1.59, 41.37) < 1$.

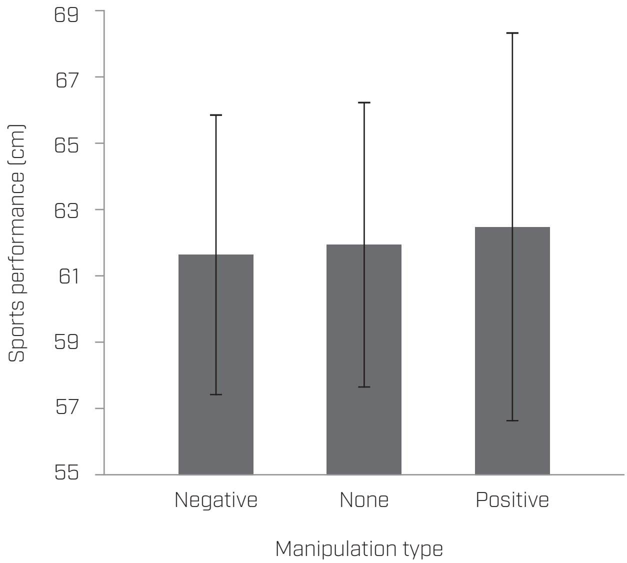


Fig. 5. Mean distance missed (cm) on the sport task after watching manipulated and non-manipulated VR replays. The error bars represent standard errors.

Discussion

Whereas previous research focused primarily on false information about passively observed events, in the present study we aimed to investigate whether memory for one's own physical performance can be altered by means of false, manipulated replays of these events in VR, displayed from a first-person viewpoint. The inherent characteristics of VR (e.g., user-specific viewpoints and a wide, three-dimensional field of view) provide a great sense of immersion, which makes it a very rich form of media (Segovia & Bailenson, 2009). We therefore expected that watching the manipulated replays would alter memory, so that the manipulated replays would be considered equally accurate representations of actual performance as the non-manipulated ones.

In the present study we further explored the possibility of using the misinformation effect beneficially, by investigating whether it can affect feeling of competence, as well as subsequent sports performance.

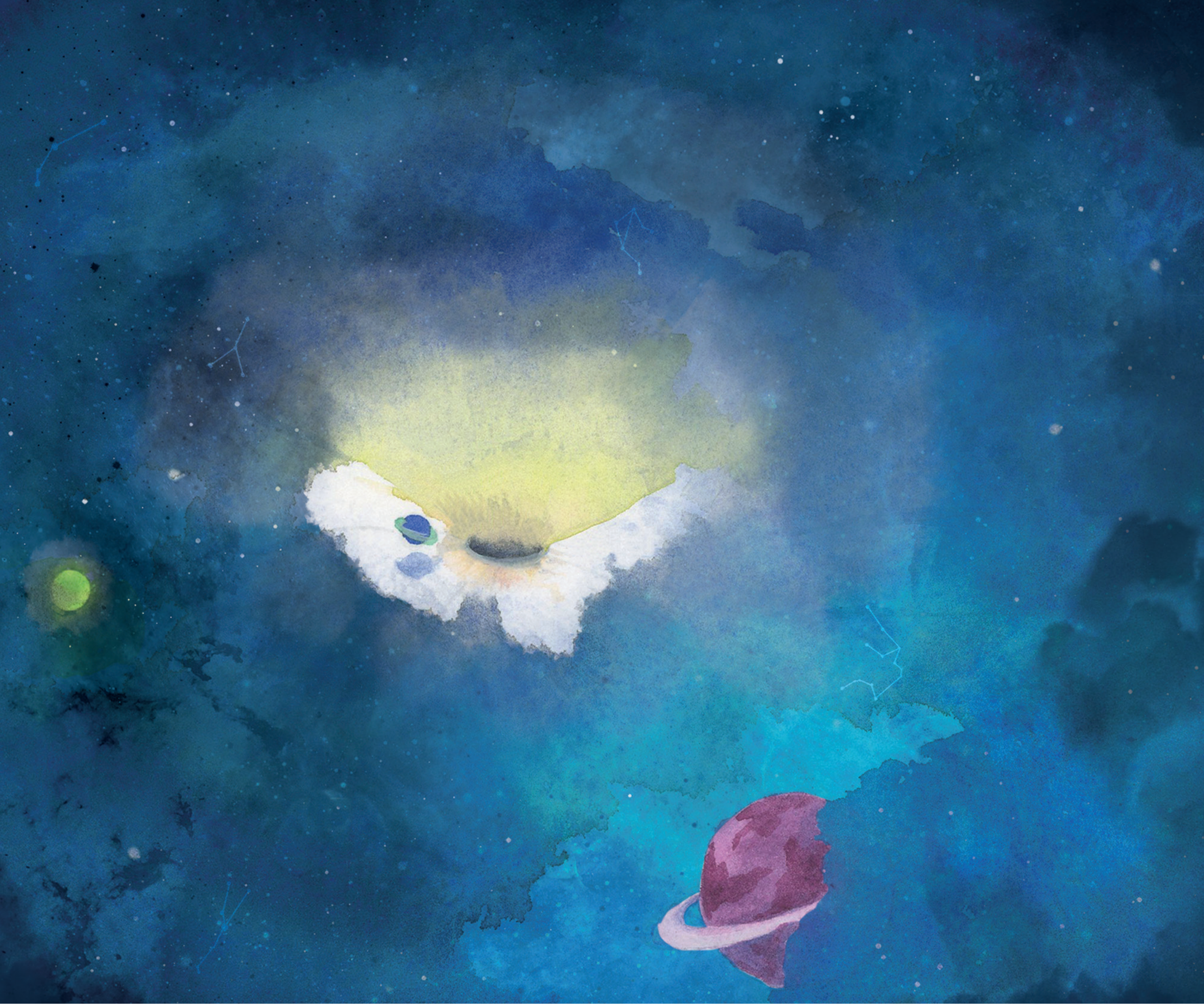
Memory alteration

As expected, the manipulated replays were considered equally accurate representations of actual performance as the non-manipulated ones. However, the positive manipulations were considered more realistic than the negative manipulations, and a similar trend was found for the positive manipulations in comparison to the non-manipulated replays. It could be caused by a ‘self-serving bias’, which can be described as any cognitive or perceptual process that is distorted by the need to maintain and enhance self-esteem (Sherrill, 2008). In the present study, participants may have rejected the negative manipulations by rating them as less realistic, thereby maintaining their self-esteem. Also, people generally tend to distort their memories in a positive way (Loftus, 1982). The positive manipulations may have confirmed the correctness of such ‘prestige-enhancing’ memories, leading to higher ratings for these replays.

Feeling of competence and sports performance

The type of replay manipulation positively correlated with feeling of competence; negative manipulations decreased participants’ feeling of competence, whereas positive manipulations increased it. As the replays are a form of feedback on personal sports performance, this finding fits nicely with previous sports research, which showed that coach feedback is positively correlated with feeling of competence (Allen & Howe, 1998). We suggest it could be worth exploring whether manipulated VR reconstructions of memories can be used for therapeutic purposes, such as prevention or treatment of performance anxiety following bad performance in a football match or other sports competition.

According to self-determination theory (Ryan & Deci, 2000), an increased feeling of competence leads to an increase in intrinsic motivation, which in turn is positively correlated with quality of performance. Manipulation type, however, did not influence sports performance in the present study. Perhaps this lack of an effect on performance was caused by the fact that only amateur football players participated, who were not able to translate changes in feeling of competence into better or worse performance due to a lack of skill. Another explanation could be that the effect of feeling of competence on motivation was too small. The strength of the relationship between feeling of competence and motivation to perform should be addressed in further research.



CHAPTER 6

Manipulating spatial distance in virtual reality: Effects on walking performance in patients with intermittent claudication

Published as:

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ABSTRACT

Research indicates that the manipulation of spatial distance between objects in a previously experienced environment may go unnoticed when the categorical information of these objects, such as their order, matches that of memory for the environment. Using a repeated measures design, we investigated whether manipulations of spatial distance in virtual reality (VR) can influence treadmill exercise performance (i.e., walking distance) in patients with intermittent claudication; a cramping pain or discomfort in the legs, which occurs during exercise. Participants (N = 19) carried out 4 treadmill exercise sessions; 1 without VR and 3 with a VR environment to move through while walking. They were instructed to walk until the pain forced them to stop. All VR sessions contained the same environment, but in the second and third session it was 'stretched' and 'compressed'. Walking distance was not influenced by the mere addition of VR. However, both VR manipulations led to greater walking distance than the VR baseline session and participants walked furthest when presented with the stretched environment. The results indicate that the manipulation of spatial distance in VR can be of clinical relevance; a finding that may be applied in the development of future medical applications.

Introduction

Virtual reality (VR) is a computer technology that typically allows the user to look around in an artificial world, move through it, and interact with it. VR is thereby capable of inducing a strong 'sense of presence', which is commonly described as the feeling of being physically situated within a spatial environment portrayed by a medium (see Wirth et al., 2007). It is thought that an increased sense of presence magnifies user effects (e.g., the extent to which users respond realistically to the mediated environment) and that this, in turn, increases the effectiveness of applications (Cummings & Bailenson, 2016). This is not only of great value for the entertainment industry, but has also proven to be useful in the field of healthcare, for clinicians and patients alike. For instance, VR exposure therapy has helped people overcome specific phobias, such as fear of heights or spiders, since at least the mid-1990s (Rothbaum et al., 1995; for meta-analyses, see e.g., Morina, Ijntema, Meyerbröker, & Emmelkamp, 2015; Parsons & Rizzo, 2008). Another popular example is the use of VR as a pain reduction technique in the treatment of acute pain (Garrett et al., 2014), such as pain experienced during wound care by patients with severe burn injuries (Hoffman et al., 2008; Hoffman, Patterson, Carrougher, & Sharar, 2001).

Overall, VR in healthcare is still in its early days in terms of novel treatment paradigms. In case of VR exposure therapy, the added value over real-life (in vivo) exposure seems to be that it allows exposure to all kinds of real-world situations (e.g., standing on top of a building or being surrounded by spiders) at a single location, thereby providing a cost- and time-efficient alternative. There are other advantages, such as that VR allows control over the artificial stimuli (i.e., the virtual environment can be adjusted or abandoned at any given moment), but the main benefits seem to be of practical nature. In case of VR as a pain reduction technique, being able to induce a sense of being situated within a VR environment serves a different purpose. Although the exact mechanisms remain unclear, VR is generally hypothesized to be capable of reducing pain by means of distraction (Garrett et al., 2014). Conscious attention is required to process pain signals and VR can provide an engaging environment which draws a lot of attentional resources, leaving less attention available to process these pain signals (Hoffman et al., 2001).

Although VR is used effectively in the aforementioned examples, its most valuable feature may be that it is not subject to the same limitations as the physical world; VR allows the user's environment to be manipulated in ways that are difficult or even impossible to realize otherwise. It is therefore relevant to establish which manipulations VR allows for, to test their user effects, and to explore whether these manipulations can be of clinical relevance. Such knowledge may serve as guidelines for the development of future medical applications and the aim of our study was to contribute in this line of research. Cuperus and van der Ham (2016) previously investigated the effect of manipulating the spatial distance between objects in VR on memory. In this study, participants took shots at a target on a football field and were shown three different types of VR replays of their performance on this task; one accurate representation of actual performance and two manipulated representations in which the distance between the ball and the target was adjusted. One manipulation made performance seem worse (miss distances multiplied by 1.5) and the other made performance seem better (miss distances multiplied by 0.5). Interestingly, however, all three were considered equally accurate representations of actual performance, indicating that the distance manipulations were not noticed. Moreover, the type of manipulation positively correlated with participants' feeling of competence with respect to the task.

The results of this football study can be explained in light of how people memorize spatial relations between objects and between objects and themselves. Kosslyn (1987) proposed a distinction between the representations of coordinate (metric) and categorical spatial relations (e.g., the side of an object in relation to another object). Typically, people are not very accurate in memorizing the precise metric properties of objects and their locations, especially after longer temporal delays. The same holds true for memory retrieval, which is a reconstructive process (Bartlett, 1932) that is susceptible to misleading, suggestive information (Loftus, 2005). The VR replays in the study by Cuperus and van der Ham matched participants' memory in terms of the categorical spatial relations that were of main importance to the task (i.e., the side of the target along which the ball passed for each shot), which could well explain why the manipulations were not noticed.

In the present study, we investigated whether the manipulation of spatial distance in VR can also be of clinical relevance. We focused on a specific clinical population: patients with intermittent claudication (IC). IC is a cramping pain or discomfort in the legs, which occurs during exercise, such as walking, and is relieved with rest (Lane, Ellis, Watson, & Leng, 2014). Most often it is a symptom of peripheral artery disease, in which the arteries that supply blood to the limbs are obstructed due to atherosclerosis. Current guidelines appoint supervised exercise therapy, consisting of treadmill or track walking to moderate claudication pain, as primary treatment for patients with IC. A meta-analysis shows that this generally decreases patients' functional impairment, which is usually quantified as the distance that patients can walk before pain forces them to stop (Lane et al., 2014). However, motivating patients for such a painful exercise program forms a barrier to widespread prescription of supervised exercise therapy for all patients diagnosed with IC (Fokkenrood et al., 2014).

First, we tested whether VR can serve as a pain reduction technique in patients with IC. Up till now, all studies about pain and VR focused solely on pain outside control of the patient (e.g., pain experienced during wound care). What is special about claudication pain is that it is produced 'actively' by walking. Based on previous analgesic effects of VR on pain (for a review, see Garrett et al., 2014) we expected that an engaging VR environment would also distract patients with IC from the pain in their legs during treadmill exercise and that this would lead to greater exercise performance (i.e., greater walking distance), thereby possibly increasing therapy effectiveness. Next, we examined whether manipulating the spatial characteristics in the VR environment in two subsequent VR treadmill exercise sessions would influence exercise performance further, by 'stretching' and 'compressing' the environment in the direction of its walkway. When learning a route, people initially build up knowledge of landmarks. Metric properties such as distance or temporal duration are believed to be acquired gradually with experience (McNamara, Sluzenski, & Rump, 2008), so in interpreting the environment in subsequent VR sessions we expected patients to rely mostly on the categorical information they acquired earlier. Because this information (i.e., landmarks and their order) matched that of the first VR session, we expected that the spatial manipulations would not be noticed (Cuperus & van der Ham, 2016). The subsequent sessions also included a flag which marked the location of the previously reached walking distance (± 10%, depending on condition), thereby setting visual, attainable goals. We reasoned that patients would be motivated to pass or at least reach their prior record, leading to increased treadmill walking distance in the stretched VR condition and decreased walking distance in the compressed VR condition. Finally, aside from its effects on performance, we explored whether treadmill exercise with VR would be considered more enjoyable than exercise without VR.

Material and methods

Participants

To be eligible, participants had to be diagnosed with IC and follow supervised treadmill exercise therapy twice a week at one of three participating physiotherapy clinics. Exclusion criteria were motion sickness, balance problems, dementia and a history of heart disease or epilepsy. A total of 23 patients were recruited by their treating therapists. Data of three participants was excluded from analyses, as they did not finish all experimental sessions due to circumstances unrelated to IC or the experiment. Data of one participant was excluded because it contained a walking distance that was considered an outlier (outside the range of $M \pm 2.5$ SD for the relevant measure and condition). The mean age of the remaining 19 participants (six male, 13 female) was 72.6 years (range 49–92; SD = 11.6). Comorbidity consisted of chronic obstructive pulmonary disease (N = 6), diabetes mellitus type 2 (N = 4), peripheral neuropathy (N = 2), hypertension (N = 2), rheumatoid arthritis (N = 2), thyroid deficiency (N = 1) and hypercholesterolemia (N = 1).

Ethical approval

This study adhered to the Declaration of Helsinki (World Medical Association, 2013). The Medical Ethical Committee Noord-Holland considered the study not to fall under the Medical Research Involving Human Subjects Act (reg. no. M016-009), because participants were not subject to procedures and were not required to follow rules of behaviour.

Task and measures

Treadmill exercise task

Participants carried out a treadmill exercise task under four different conditions. They were instructed to walk as far as possible and to report the moment they wished to stop because the pain forced them to (i.e., their maximum walking distance) verbally.

Questionnaire

After all exercise tasks were finished, participants were asked to rate how fun they considered the exercise sessions with VR and the one without, on two 100 mm paper visual analogue scales (VAS) that ranged from 0 (no fun at all) to 100 (extremely fun; for similar measures of fun, see e.g., Hoffman et al., 2004; Wallot, Mitkidis, McGraw, & Roepstorff, 2016). The questionnaire also contained an open question about what they believed was being tested, to check if they noticed the VR environment was manipulated in the second and third VR session.

Conditions

Other than during regular treadmill exercise, in the no VR condition the treadmill's information display was covered for participants so that no information about walking time or distance was available to them. Also, the treating therapists did not go into conversation with participants during exercise, but remained silent and out of participants' vision. In addition to this, in the VR baseline condition participants moved through the VR environment while walking on the treadmill. This environment consisted of a colourful forest with a walkway and contained several dynamic elements that were intended to distract from the pain during walking, such as animals crossing the path and the trees constantly changing colour over time (see Fig. 1). Sound was found to enhance the analgesic effect of VR (Johnson & Coxon, 2016), so sounds were included of animals and of the wind blowing through the trees. In two subsequent VR conditions a flag was added to the same environment at the location matching the walking distance reached in the prior VR session. Furthermore, the whole environment, including the newly added flag, was stretched and compressed in the direction of the walkway by 10% (in comparison to the baseline environment), thereby increasing (VR increased) and decreasing (VR decreased) the distance between all objects.

Fig. 1. Screenshots of the VR (baseline) environment that participants moved through while walking on the treadmill.

Because the VR baseline condition needed to be followed by the other VR conditions, we were limited in our ability to randomize the order of conditions. Participants who started their first session without VR were offered the VR baseline condition in the second session. For the ones who started with the VR baseline condition, the last exercise session contained no VR. Furthermore, for half of all participants VR baseline was followed by VR decreased and then VR increased and for the other half it was followed by VR increased and then VR decreased. This amounted to a total of four different orders of conditions to which participants were assigned based on order of entry:

1. No VR → VR baseline → VR decreased → VR increased
2. No VR → VR baseline → VR increased → VR decreased
3. VR baseline → VR decreased → VR increased → No VR
4. VR baseline → VR increased → VR decreased → No VR

Procedure

The experiment took place in the three clinics where participants normally carried out their treadmill exercise and consisted of four treadmill exercise sessions; one for each condition, separated from each other by periods of three days. To make sure that the same procedure was followed in each clinic, all measurements were carried out by the same experimenter. The treating therapists were always present as well, so they could intervene if deemed necessary (but this was never the case). To reduce environmental noise, no other people were allowed inside the exercise area and all doors and windows were closed. Furthermore, the temperature was always set to 21 °C and participants' sessions were all scheduled at the same time for each day.

Before the first exercise session, participants read the information sheet and signed the consent form. The information sheet stated that the goal of the experiment was to test the effects of moving through a VR environment on walking performance several times. Participants were verbally instructed about the experiment, after which they took a seat for 5 min. This way they could recover from any possible fatigue caused by walking up the stairs towards the exercise area for instance. They then stepped onto the treadmill for the first exercise session. The ones who started with the VR baseline session also put on a VR headset through which the VR environment was visible during exercise. The treadmill was then started at participants' usual treadmill exercise speed. In the VR session, this speed was also manually entered in the settings of the application so that the visuals would match participants' walking speed. The distance value (measured in meters) matching the verbally reported moment participants wished to stop was read from the treadmill's information display, after which the treadmill was turned off. The following three sessions followed the same procedure and participants filled out the questionnaire after the last session. They were then informed about the actual goal of the experiment and were told in which order the different VR conditions were offered.

Materials

The VR application was developed in collaboration with Triple (Alkmaar, the Netherlands) and Gamedia (Alkmaar, the Netherlands). The VR headset we used was the first consumer edition of the Oculus Rift (Oculus VR; Menlo Park, California) and the PC we used to run the application on was equipped with an NVIDIA GeForce GTX 1070 graphics card (NVIDIA; Santa Clara, California). This allowed the application to run at a high frame rate (90 FPS). Life Fitness F3 (Life Fitness; Rosemont, Illinois) fixed-speed treadmills were used in all three clinics. The main statistical analyses were carried out using IBM SPSS Statistics 23 (IBM; Chicago, Illinois). We used G*Power 3.1.9.2 for Windows (Düsseldorf, Germany) to carry out the power analyses.

In VR, there is a perceptual distortion of the speed of optic flow. Whereas in normal walking the ratio of optic flow to speed of walking, known as 'visual gain', is 1:1, in VR the optic flow needs to be relatively faster for it to appear normal (Powell, 2011). Optimal perceived visual gain was reported to be as low as 1.3:1 (Durgin et al., 2005) and as high as 2:1 (Kassler, Feasel, Lewek, Brooks Jr, & Whitton, 2010). Not only is it dependent on several setup-related factors, such as the inclusion of near-space objects in VR (Nilsson, Serafin, & Nordahl, 2014) or the geometric field of view size (Nilsson, Serafin, & Nordahl, 2015), but there is also considerable variation between individuals in the perception of visual gain (Durgin et al., 2005). We set the visual gain to 1.3:1 in our experiment. Participants were told that this ratio could be adjusted if it felt unrealistic, but none of them reported this to be the case.

Data analyses

As participants differed from one another in their degree of functional impairment, we did not use absolute walking distances in the analyses. Instead, for each participant we divided the walking distance of each session by the total walking distance of all four sessions and multiplied these scores by 100, allowing a comparison of relative differences in performance between participants. For the hypothesis that the addition of VR would lead to increased walking distance, these scores were then compared with a paired samples *t*-test (no VR vs. VR baseline). Second, we analysed the answer to the open question of the questionnaire by separating and describing answers indicating that participants noticed any kind of difference between the VR environments from answers indicating that they noticed no difference at all. Next, a repeated measures ANOVA was carried out to test whether the manipulation of spatial distance influenced walking distance, with manipulation type (VR baseline vs. VR increased vs. VR decreased) as within-subjects factor. We also conducted a post-hoc power analysis based on the outcome of the repeated measures ANOVA to determine the power we achieved with the sample that we included in the study. This was followed by an a priori power analysis to indicate the necessary sample size for an adequate reproduction of the results. Finally, to test whether VR was considered more enjoyable, the VAS scores on subjective experience of fun (no VR vs. VR) were compared with a paired samples *t*-test.

Results

Fig. 2 shows the mean walking distance for each treadmill exercise condition. The paired samples *t*-test showed that the average walking distance in the first exercise session with VR did not significantly differ from the average distance in the session without VR, $t(18) = .67$, $p = .51$. This suggests that the mere addition of VR did not influence exercise performance.

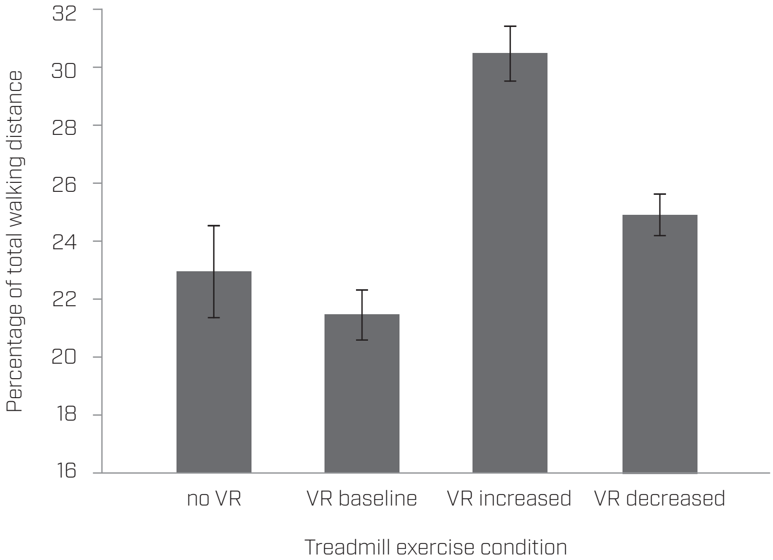


Fig. 2. Mean percentage of total walking distance for each treadmill exercise condition. The error bars represent standard errors.

None of participants' answers to the open question of the questionnaire indicated that they noticed any kind of difference between the three VR environments. It therefore seems that the spatial manipulation of distance in the second and third VR session were not noticed.

The repeated measures ANOVA showed that walking distance was significantly influenced by type of manipulation, $F(2, 36) = 32.55$, $p < .01$, $\eta_p^2 = .64$. Post-hoc Bonferroni corrected t-tests showed that the average distance in the baseline VR session was significantly smaller than the average distance in both the VR increased condition, $p < .01$, and VR decreased condition, $p < .01$. Also, participants walked significantly further in the VR increased condition than in the VR decreased condition, $p < .01$.

With an effect size f of 1.33, alpha set at .05, correlation among repeated measures at .50 and nonsphericity correction at 1.00, the post-hoc power analysis showed that the achieved power was 1.00. The a priori power analysis further indicated that in order to adequately reproduce these results, a study should include at least eight participants.

Finally, the second paired samples t-test indicated that participants rated the exercise session without VR ($M = 49.84$, $SE = 5.67$) as significantly less fun than the sessions with VR ($M = 76.89$, $SE = 4.94$), $t(18) = 4.42$, $p < .01$, $d = 1.02$.

Discussion

The most valuable feature of VR may be that it is not subject to the same limitations as the physical world; it allows the user's environment to be manipulated in ways that are difficult or even impossible to realize otherwise. The main aim of our study was to investigate whether the manipulation of spatial distance in VR can be of clinical relevance and this was tested in patients with IC. Based on what we know about the analgesic effects of VR on pain from other studies, we first tested whether VR can serve as a pain reduction technique in patients with IC during treadmill exercise, leading to increased exercise performance. Second, we examined whether manipulating the spatial characteristics in the VR environment in two subsequent VR treadmill exercise sessions would influence performance further.

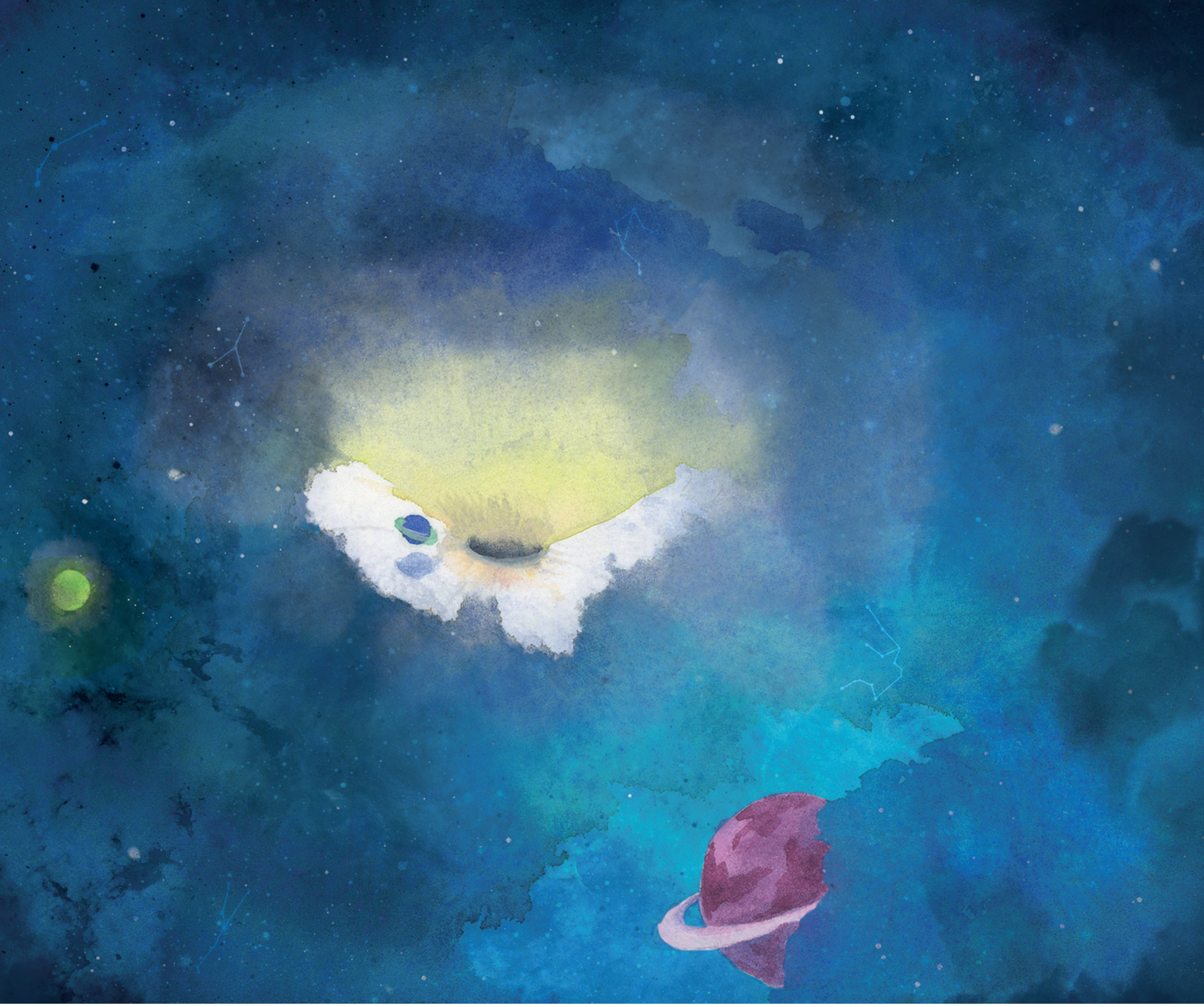
VR is generally hypothesized to be capable of reducing pain by means of distraction (Garrett et al., 2014). We expected that an engaging VR environment would also distract patients with IC from the pain in their legs during treadmill exercise and that this would lead to increased treadmill exercise performance. However, we found that walking distance in the first exercise session with VR did not differ from the distance in the session without VR, which suggests that exercise performance was not influenced by the addition of VR. One explanation for this may be found in that claudication pain builds up gradually during exercise. Research suggests that pain competes with other attention-demanding stimuli for an overlapping set of limited cognitive resources (Buhle & Wager, 2010; Moriarty, McGuire, & Finn, 2011), which means that as pain increases, the effectiveness of distraction may decrease. Perhaps the distractive elements of the VR application we used were not intense enough to distract participants from the higher levels of pain towards the end of exercise. We therefore do not rule out the possibility that a more distracting VR environment, or an environment that becomes more intense as pain increases, can increase exercise performance in patients with IC and we believe this is worth further investigation.

In two subsequent VR conditions, the whole environment was stretched and compressed in the direction of the walkway. Because the categorical information (i.e., landmarks and their order) in these sessions matched that of the baseline VR session, we expected that these spatial manipulations would not be noticed (Cuperus & van der Ham, 2016). The answers to the open question of the questionnaire indicated that this was indeed the case. The subsequent sessions also included a flag which marked the location of the walking distance reached in the prior VR session (± 10%, depending on condition), thereby setting visual, attainable goals. We reasoned that patients would be motivated to pass or at least reach their prior record, leading to increased walking distance in the stretched VR condition and decreased distance in the compressed VR condition. This was partially confirmed; the results showed that participants walked furthest when presented with the stretched environment, but also that they walked least in the VR baseline session, instead of in the session with the compressed environment. Although a possible criticism might be that the sample size of the present study was on the small side, our power analyses showed that an adequate reproduction of these effects requires only about half the number of participants we tested.

A probable explanation for the weaker performance in the baseline session seems to be that a lack of visual goals in this session resulted in lower motivation and, in turn, smaller walking distance. More important, however, is the observation that both the second and third VR session contained the same visual goal, while participants walked further with the stretched environment. This is interesting, because it seems that they did not notice the difference between the different conditions, which indicates that treadmill exercise can benefit from the increase of spatial distance in VR. However, the link between motivation, pain, and walking distance comes into question here; did participants reach greater distances because they were motivated to surpass prior records and/or did they experience more pain post exercise? In contrast, if motivation was lower in the baseline condition, this may not only have resulted in smaller walking distance, but also in less pain. Measures of motivation and pain were not included in the study, but we do think that future studies should take these into account. Also, we suggest that future research should explore the boundaries of distance manipulations (i.e., to what extent do they go unnoticed and under which conditions), as well as their possible utility with respect to medical conditions other than IC.

Conclusion

Taken together, the results of our study indicate that the manipulation of spatial distance in VR can be of clinical relevance; a finding that may be applied in the development of future medical applications. Furthermore, treadmill exercise with VR was considered more enjoyable than exercise without VR, which in itself is an indication that therapy can benefit from this type of VR applications.



CHAPTER 7

Memory-related perceptual illusions directly affect physical activity in humans

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ABSTRACT

Perceptual illusions help us understand deficits in human perception, but they also have the potential to serve as treatment/rehabilitation methods; e.g., to alleviate phantom limb pain. Treatment effects are usually the direct result of a mismatch between false visual feedback and somatosensory/proprioceptive feedback. We aimed to influence physical activity (walking distance) using a 'memory-related' perceptual illusion that relies on a mismatch between a spatially manipulated virtual reality environment and a weakness of memory for a similar, previously experienced environment. Participants' main task was to reproduce a baseline distance three times, by walking on a treadmill while moving through a virtual reality environment. Depending on condition, the environment was either stretched or compressed relative to the previous session, but participants were not informed about these manipulations. Because false, suggestive information can lead to alterations in memory, especially when conveyed through 'rich' forms of media such as virtual reality, we expected each manipulation to alter memory for the previous environment(s) and we hypothesized that this would influence walking distance. The results for the first time showed that memory-related perceptual illusions can directly affect physical activity in humans. The effects we found are substantial; stretching previously experienced virtual environments led participants to almost double their initial walking distance, whereas compressing the environments resulted in about half of the initial distance. Possible clinical applications arising from these findings are discussed.

Introduction

Visual perception was traditionally thought of as a passive, flawless process, in which our eyes function as a perfect camera. However, the study of perceptual illusions demonstrated that it is susceptible to error. Our brain uses other sources of information, such as memory for past events, to 'construct' a cognitive understanding of sensory information (Gregory, 1997). What makes this process even more fragile is that our memory itself is not flawless either. That is, a memory becomes labile when reactivated and may be influenced by other cognitive processes, including perception, while in this state (Dudai, 2012).

There are obvious downsides to the fallibility of human perception and memory, such as the challenges they present for the justice system, but it can also be used to our benefit. In the 1990s, for instance, a mirror visual feedback technique was developed in an attempt to alleviate phantom limb pain (Ramachandran & Rogers-Ramachandran, 1996; Ramachandran, Rogers-Ramachandran, & Cobb, 1995). It typically involves the use of a mirror across the patient's midline to create the illusion of having two complete limbs (Moseley, Gallace, & Spence, 2008). Such a technique has its limitations, because it relies on the presence of an unaffected limb and only allows for symmetric actions. A virtual reality (VR) setup is not necessarily subject to such constraints and may thus provide a better alternative (for a review, see Dunn, Yeo, Moghaddampour, Chau, & Humbert, 2017). Seeing a virtual body from a first-person perspective can induce the illusion of ownership over (parts of) this virtual body (Slater, Spanlang, Sanchez-Vives, & Blanke, 2010; cf. the classic 'rubber hand' illusion; Ehrsson, Spence, & Passingham, 2004). Moreover, this illusion can still be effective when the virtual body proportions are manipulated, because our body representation is highly plastic; even when a virtual limb triples in length, the illusion may not break (Kilteni, Normand, Sanchez-Vives, & Slater, 2012). Such false visual body size feedback can further modulate pain (Mancini, Longo, Kammers, Haggard, 2011), but it may also be useful, for instance, in the treatment of patients with anorexia nervosa (Keizer, van Elburg, Helms, & Dijkerman, 2016).

VR can be used to present the user with other types of false visual feedback as well, such as the manipulation of perceived walking speed. Normally, the ratio of optic flow to speed of walking, known as the 'visual gain', is 1:1. In VR, however, the optic flow needs to be relatively faster for it to appear realistic. Visual gain perception is dependent on several setup-related factors, such as the geometric field of view size (Nilsson, Serafin, & Nordahl, 2015). Optimal perceived visual gain was reported to be as low as 1.3:1 (Durgin et al., 2005) and as high as 2:1 (Kassler, Feasel, Lewek, Brooks Jr, & Whitton, 2010). Extremely low ratios (below 1:1) can be used to increase walking speed (but at the expense of realistic perception; Powell, 2011). VR allows for the manipulation of perceived orientation in a similar fashion. In a technique called 'redirected walking', real-world rotations are transformed into increased or decreased rotations in the virtual environment. This allows users to walk through large-scale virtual environments while they physically remain in a small workspace; users can be redirected on a circular arc with a radius of at least 22 m while they believe that they are walking straight (Steinecke, Bruder, Jerald, Frenz, & Lappe, 2010).

These false visual feedback examples illustrate a clear strength of VR, namely that it is not subject to the limitations of the physical world. What they have in common is that their effects are the direct result of a mismatch between false visual feedback and somatosensory/proprioceptive feedback. In contrast to this, Cuperus et al. (2018) tested a perceptual illusion that relies on a mismatch between a manipulated VR environment and a weakness of memory for a similar, previously experienced environment. Participants in their study were patients with intermittent claudication; a cramping pain or discomfort in the legs, which occurs during exercise. They walked on a treadmill while moving through a VR environment three times and were instructed to walk until the pain forced them to stop before each session. All VR sessions contained the same environment, but in the second and third session it was 'stretched' and 'compressed' (or vice versa) in the direction of its walking trail (by 10% in comparison to the baseline environment). These sessions also included a flag which marked the location of the previously reached walking distance (± 10%, depending on condition), thereby setting visual, attainable goals. None of the participants noticed these manipulations, while they did influence performance; participants walked furthest when interacting with the stretched environment. The authors explained these results in light of the distinction between how we memorize metric and categorical spatial relations (e.g., the side of an object in relation to another object), as proposed by Kosslyn (1987). People are typically not very accurate in memorizing the precise metric properties of objects and their locations, especially after longer temporal delays. In interpreting the environment in the second and third VR sessions, participants were therefore expected to rely mostly on the categorical information they acquired earlier and this information (landmarks and their order) matched with the previous VR session(s).

The study by Cuperus et al. (2018) indicated great potential for the use of 'memory-related' perceptual illusions to influence clinically relevant physical activity. In the present study, we assessed whether these findings generalize to healthy individuals, because patients with intermittent claudication typically have several comorbid conditions that may affect memory. Furthermore, even if memory was not impacted, participants' walking distance may have been influenced solely by the presence of the virtual flag; i.e., without linking the presented visual information to memory. For this reason, and the fact that people normally do not easily reach a pain barrier while they walk on a treadmill, we used a different task in which participants had to reproduce a baseline walking distance. This approach also allowed us to investigate whether the same manipulation can be applied multiple (three) times in a row, with very short time intervals. Because false, suggestive information can lead to alterations in memory (Loftus, 2005), especially when conveyed through 'rich' forms of media such as VR (Segovia & Bailenson, 2009), we expected each manipulation to alter memory for the previous environment(s). We therefore hypothesized that participants in the stretched condition would increase their walking distance each session, whereas participants in the compressed condition would decrease their walking distance each session. Next, in order to explore whether the manipulations also take effect on a basal motoric level, we tested their influence on step length (distance divided by number of steps). Finally, we made a distinction between participants who may have noticed at least some kind of spatial manipulation during the experiment and participants who did not notice anything at all, and explored whether they behaved differently in terms of walking distance, step length, and a landmark memory task.

We aimed to influence physical activity using a memory-related perceptual illusion that relies on a mismatch between a spatially manipulated VR environment and a weakness of memory for a similar, previously experienced environment. The effects we found are substantial and the findings of our study can be applied in the development of novel clinical applications.

Materials and methods

Participants

Participants were recruited via the website proefbunny.nl and social media. Eligible participants were at least 18 years old and individuals with psychiatric disorders, proneness to motion sickness, a (known) history of heart disease, and/or epilepsy were excluded. A total of forty participants (18 male, 22 female) with a mean age of 26 years (range 18–35; *SD* = 4.1) took part in the experiment. They were randomly distributed over the stretched and compressed conditions.

Ethical considerations

The study was approved by the Faculty Ethics Review Board of University of Amsterdam's Faculty of Social and Behavioural Sciences (2017-BC-8133), where the study was conducted. The research was carried out in accordance with the provisions of the Declaration of Helsinki (World Medical Association, 2013).

Tasks and measures

Participants' main task was to reproduce a certain distance three times, by walking on a treadmill while moving through a VR environment. The spatial features of this environment were manipulated during the task; the environment was stretched in the direction of its walking trail by a factor 1.2 relative to the previous session for half of the participants, and for the other half it was compressed by a factor 1.2 relative to the previous session (cf. Cuperus et al., 2018), but participants were not informed about these manipulations. Participants were instructed to also play a game (a crystal collection task; see below) while they walked. This dual-task approach was used to mask the actual goal of the experiment, which was to test whether the spatial manipulations influenced walking distance and step length. To check the effectiveness of this masking, we included a questionnaire at the end of the experiment. A number sequence task was used as a distracting filler task between walking sessions. To be able to interpret the results of our study within a spatial memory framework, we deemed it important that participants did not deviate in their ability to make accurate estimates of metric properties. A metric estimation task was therefore included, and we also added a landmark memory task to assess memory for the categorical information of the VR environment.

Walking distance reproduction task

Participants walked on a treadmill four times while moving over a straight trail in a virtual environment that was presented through a VR headset. This environment consisted of a colourful forest that contained several elements (landmarks) which were encountered in a particular order, such as a pair of giraffes and a pyramid-like structure (cf. Cuperus et al., 2018). In addition to this, the environment contained a fixed amount of crystals (one per 35 m on average) that appeared at varying locations (e.g., in a tree, alongside the trail, or in the mouth of an animal; Fig. 1). The entire environment, including its landmarks, was identical for each walking session, apart from its metric properties. That is, depending on condition, it was either stretched or compressed by a factor 1.2 relative to the previous session, in the direction of the trail (resulting in stretch/compress factors 1.2, 1.44, and 1.73 compared to the first session; Fig. 2). However, the treadmill was set at the same speed for each session (3.6 km/h); i.e., the treadmill speed was constant with respect to the lab environment.

Prior to the first walking session, participants were instructed to collect as many crystals while walking as possible before the experimenter would turn off the VR application and the treadmill. These crystals could be collected by being kept in the centre area of the field of vision for 1 s; i.e., without eye tracking. Participants were also asked to pay close attention to the environment, because in the three walking sessions that were to follow their task would not only be to collect crystals again, but also to reproduce the spatial walking distance of the first session (175 m) as accurately as possible. This was done by saying 'stop' when they felt this distance was reached, after which the experimenter turned off the VR application and the treadmill. Participants were told they would be awarded a score for both tasks at the end of the experiment.

Fig. 1. Screenshot of the VR environment; an animal crosses the trail while holding a crystal.

Number sequence task

Participants were presented with 24 sequences of five natural numbers, which all had to be continued by one correct subsequent number. They were instructed to finish as many sequences as possible within 2 min. Solving number sequence tasks is considered a prime example of inductive reasoning, because a problem solver must detect or formulate a relation or rule among elements in a series (LeFevre & Bisanz, 1986).

Landmark memory task

First, participants were asked to mark the elements they remembered crossing during the walking distance reproduction task on a list with descriptions of the six landmarks they actually crossed and of six similar elements that never appeared. One point was awarded for marking a correct element and for not marking an incorrect one (maximum score: 12). Second, participants received printed screenshots of the six landmarks and were asked to place these in the correct order of appearance. One point was awarded for each screenshot that was followed by a screenshot representing a later appearing landmark (maximum score: 5).

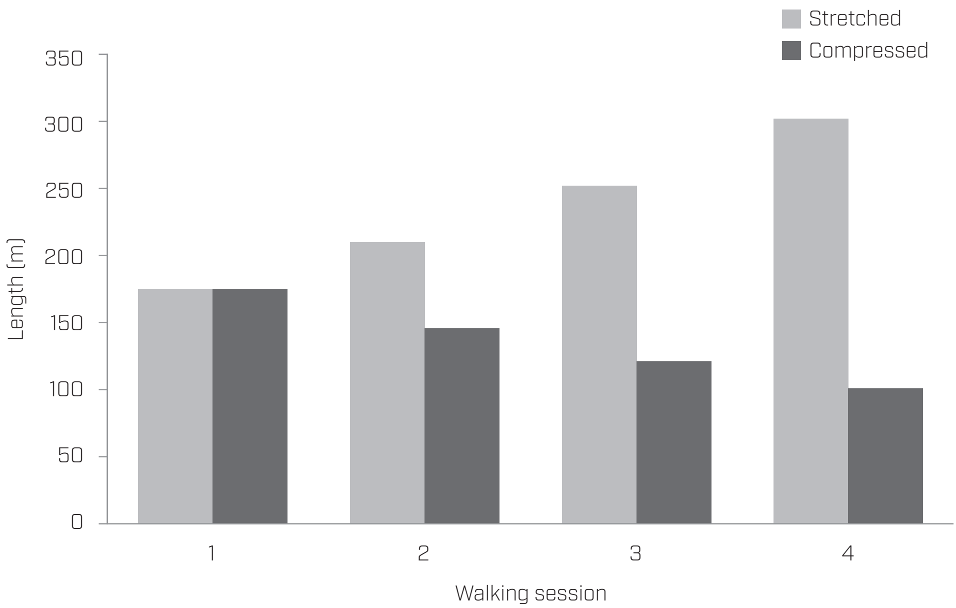


Fig. 2. Illustration of how the part of the virtual trail that participants walked in the first (baseline) session stretched or compressed over sessions (factor 1.2).

Metric estimation task

Participants were asked to verbally estimate the dimensions of several geometrically shaped objects (e.g., a cube and a cylinder) and the distances between them (in cm); three times for objects in near (peripersonal) space and three times for objects in far (extrapersonal) space. The objects had a smooth grey texture and were unshaded. Estimates in the peripersonal part of the task were made from a seated position with the objects on a desk in front of participants. Estimates in the extrapersonal part of the task were made from a standing position with the objects on the ground in front of participants (3 m between their feet and the closest object). There was no time limit for the task.

We calculated the absolute difference between each estimate and its related actual size/distance (peripersonal: 22, 9, and 20 cm; extrapersonal: 9, 40, and 100 cm). This difference was divided by the related actual size/distance and then multiplied by 100, resulting in a 'misestimate percentage' for each estimate.

Questionnaire

The questionnaire contained two open questions: (1) "Did you notice anything during the study and if so, what exactly?" and (2) "What do you think we are investigating?". Together with any relevant verbal comments during the experiment, these questions were used to make a distinction between participants that did not notice any kind of spatial manipulation and participants who may have noticed at least some kind of spatial manipulation.

Procedure

After providing written consent, participants carried out the walking distance reproduction task. To minimize the risk of falling, they were instructed to hold onto the treadmill's handles during each walking session. Walking distances were read from the treadmill's information display and steps were counted with tally marks. In between walking sessions participants carried out the number sequence task, which allowed the experimenter to set up the VR application with the correct stretch/compress factor for the next session. The last session was followed by the landmark memory task, the metric estimation task, and the questionnaire. Verbal comments indicating that participants noticed any kind of spatial manipulation during the experiment were also written down by the experimenter. Finally, participants were briefed about the actual goal of the study.

Materials

The VR application was developed in collaboration with Triple (Alkmaar, the Netherlands) and Gamedia (Alkmaar, the Netherlands). The hardware setup consisted of a Focus Fitness Jet 2 fixed speed treadmill (Focus Fitness; Venlo, the Netherlands), an Oculus Rift (first consumer edition; Oculus VR; Menlo Park, California), and a PC equipped with an NVIDIA GeForce GTX 1070 graphics card (NVIDIA; Santa Clara, California). We applied a visual gain of 1.55:1 to our experimental setup, based on a pilot experiment ($N = 10$) that followed the procedure of Powell, Stevens, Hand, and Simmonds (2011). The statistical analyses were carried out using IBM SPSS Statistics 23 (IBM; Chicago, Illinois).

Statistical analyses

There was no variance in walking distance for the first walking session, because each participant walked precisely the same distance (baseline); after 175 m was reached, the treadmill was turned off by the experimenter. For the analyses, we therefore calculated the changes in walking distance and step length (distance divided by steps) compared to baseline for each subsequent session. The difference scores were analysed in a mixed ANOVA with walking session as within-subjects factor, and condition and manipulation awareness as between-subjects factors.

Results

Sample of participants

Participants' average misestimate percentage was 14.87 (*SD* = 8.94) for the peripersonal part of the metric estimation task and 17.87 (*SD* = 11.86) for the extrapersonal part. One participant in the stretched condition scored outside the range of *M* + 3 *SD* on the peripersonal part of the task and was therefore excluded from the analyses.

Awareness of manipulation

Based on participants' verbal comments and their responses to the open questions, we concluded that 16 participants (seven male, nine female) with a mean age of 25.8 years (range 18–35; *SD* = 4.6) may have noticed at least some kind of spatial manipulation; 8 in each condition. These participants reported that they (may have) noticed differences in terms of time, speed, and/or distance between sessions.

With respect to the mixed ANOVA for walking distance, Mauchly's test indicated that the assumption of sphericity was violated ($\chi^2(2) = 23.87$, $p < .001$); therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .67$). The manipulation awareness × walking session × condition interaction was not significant, $F(1.33, 46.53) = 3.04$, $p = .054$. This interaction was not significant with respect to step length either, $F(2, 70) < 1$.

We carried out two independent samples *t*-tests to find out whether participants who noticed nothing differed from participants who may have noticed some kind of manipulation in their performance on the landmark memory task. However, these revealed no significant differences; neither on the first part of the task ($M = 11.26$, $SD = .69$; $M = 11.56$, $SD = .51$), $t(37) = -1.49$, $p = .146$, nor on the second part of the task ($M = 4.65$, $SD = .57$; $M = 4.63$, $SD = .62$), $t(37) = .14$, $p = .889$.

Walking distance

Fig. 3 shows the mean walking distance for each walking session per condition. As predicted, the interaction between condition and walking session was significant, $F(1.33, 45.19) = 160.41$, $p < .001$, $\eta_p^2 = .82$. Two separate repeated measures ANOVAs were carried out next; one for each condition. For the stretched condition, Mauchly's test indicated that the assumption of sphericity was violated ($\chi^2(2) = 18.86$, $p < .001$); a Greenhouse-Geisser correction was used ($\varepsilon = .60$). Walking distance significantly differed between walking sessions, $F(1.20, 21.55) = 75.71$, $p < .001$, $\eta_p^2 = .81$. Post-hoc Bonferroni corrected *t*-tests showed that walking distance significantly increased over sessions, $p < .001$ for each comparison. For the compressed condition, Mauchly's test indicated that the assumption of sphericity was violated as well ($\chi^2(2) = 10.70$, $p = .005$); a Greenhouse-Geisser correction was used ($\varepsilon = .69$). Again, walking distance significantly differed between walking sessions,

$F(1.38, 26.24) = 139.02$, $p < .001$, $\eta_p^2 = .88$. Post-hoc Bonferroni corrected *t*-tests showed that walking distance significantly decreased over sessions, $p < .001$ for each comparison.

Furthermore, it appears that the distances walked after the baseline session match the scaled virtual distances that are presented in Fig. 2 closely; paired samples *t*-tests revealed no significant differences between these distances, $p > .050$ for each comparison.

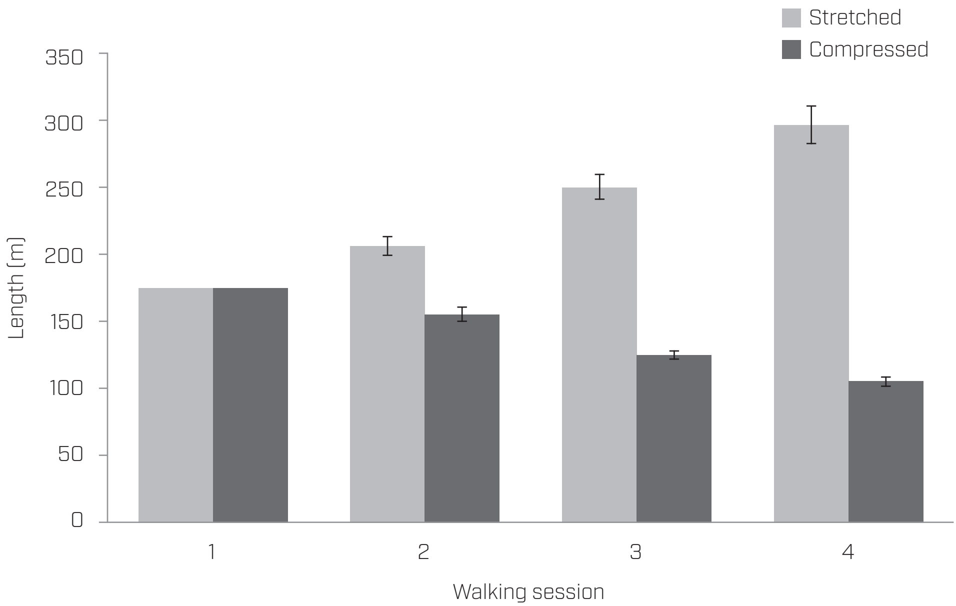


Fig. 3. Mean walking distance (m) for each walking session per condition (cf. Fig. 2). The error bars represent standard errors.

Step length

Fig. 4 shows the mean step length for each walking session per condition. The interaction between condition and walking session on participants' step length was not significant, $F(2, 70) < 1$.

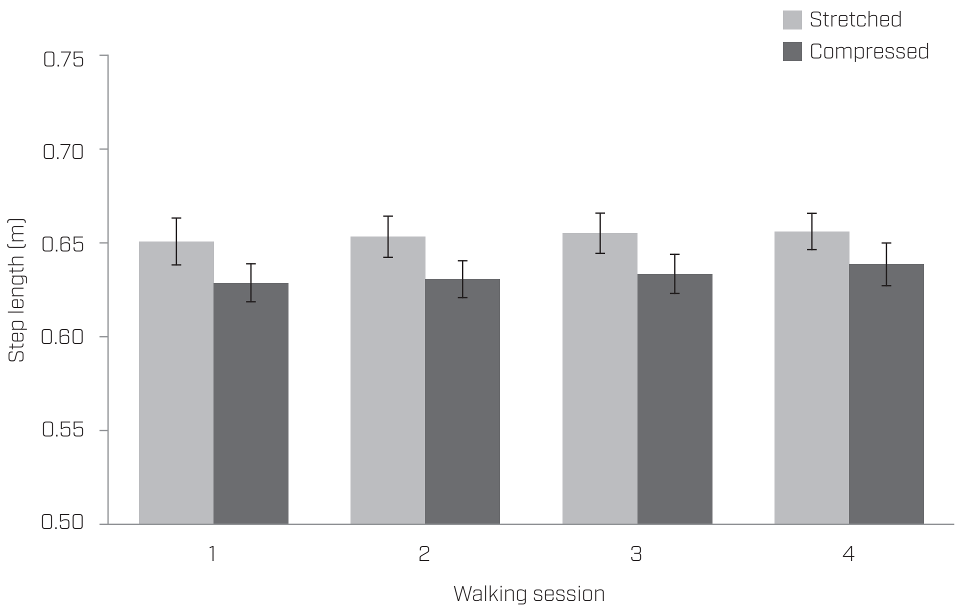


Fig. 4. Mean step length (distance divided by steps) for each walking session per condition. The error bars represent standard errors.

Discussion

Up till now, the effects of (clinical) applications using perceptual illusions to affect physical activity are the direct result of a mismatch between false visual feedback and somatosensory/proprioceptive feedback. We tested a memory-related perceptual illusion that relies on a mismatch between a spatially manipulated VR environment and a weakness of memory for a similar, previously experienced environment. The results of our study clearly indicate that the effects found by Cuperus et al. (2018) were not just a consequence of the fact that their participants consisted of older adults with several comorbid conditions that may affect memory. Moreover, they indicate that the same spatial manipulation—stretching or compressing the VR environment—can effectively be applied multiple times in a row, with very short time intervals. As predicted, participants in the stretched condition increased their walking distance each session, whereas participants in the compressed condition decreased their walking distance each session. The distances walked match the scaled virtual distances almost perfectly. Step length was not influenced by the spatial manipulations, which indicates that the manipulations did not take effect on a basal motoric level.

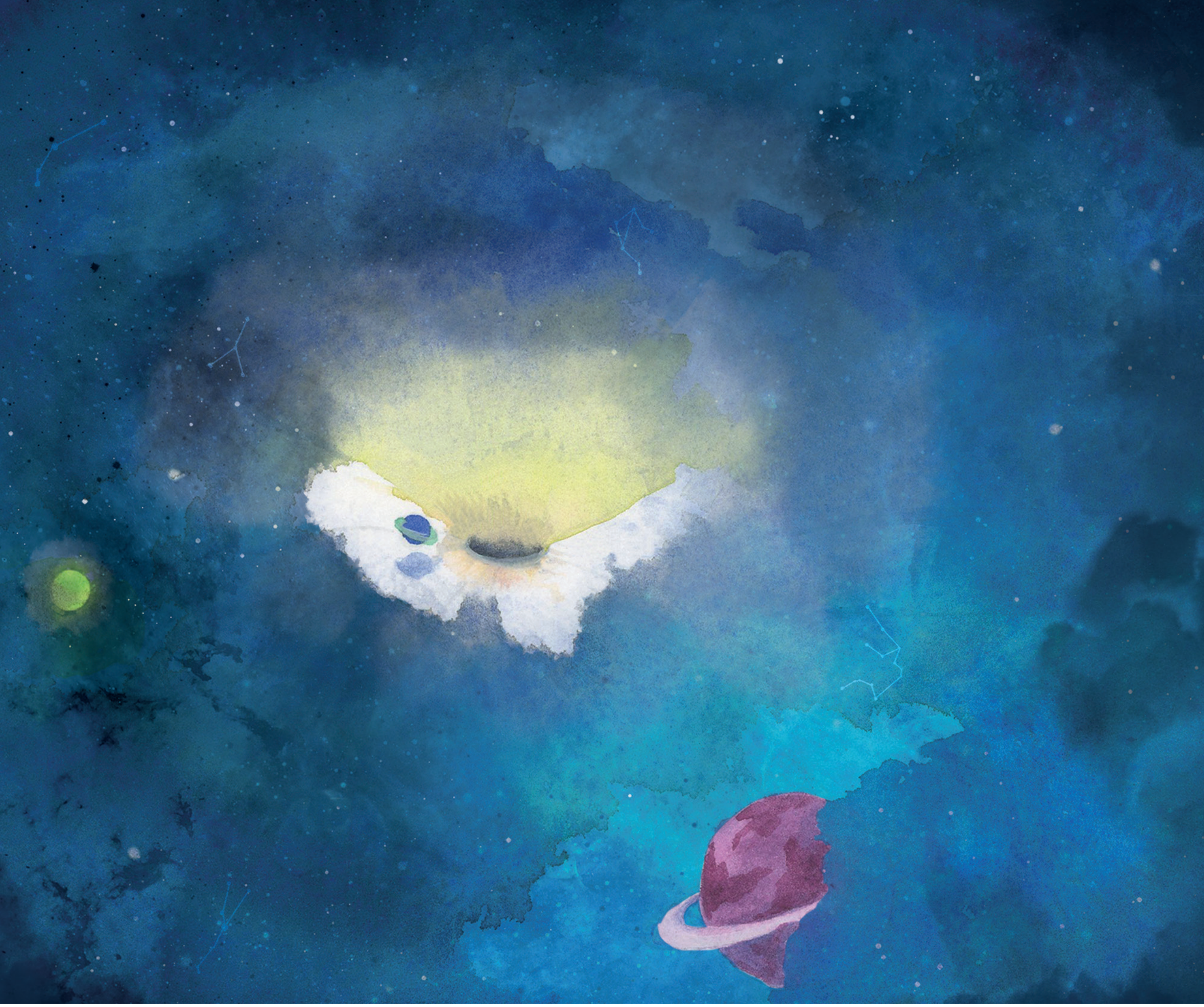
Although none of the participants were completely aware of the manipulations, sixteen participants did report having the idea that there (maybe) were differences in terms of time, speed, and/or distance between walking sessions. However, it does not seem unlikely that the tasks that followed the walking distance reproduction task (the metric estimation task in particular) had a strong influence on retrospective comments and/or answers to the open questions of the questionnaire. More importantly, this group of participants did not perform differently from participants who did not notice anything at all, indicating that their categorical knowledge of the VR environment(s) overruled any suspicions. A limitation of the study that should be noted in this respect is the potential influence of the crystal collection task on walking distance. Although the crystals were hidden in the environment and appeared at varying locations, participants may have used crystal counting as a means of distance estimation. We did not check whether participants used this method, nor did we keep track of the amount of crystals collected.

Future research should look into the further clinical utility of memory-related perceptual illusions combined with walking. In patients with Parkinson's disease, for instance, treadmill training can improve gait (Mehrholz et al., 2015) and cognitive function (da Silva et al., 2018). Perhaps the use of the spatial manipulations we used can further increase the effectiveness of treadmill exercise in this population. It might be worth exploring the use a self-paced treadmill instead of a fixed speed treadmill in this regard, because it promotes a more natural gait (Sloot, van der Krogt, & Harlaar, 2014). Moreover, this would show whether the manipulations can be used to influence walking speed (cf. Powell, 2011). The utility of memory-related illusions outside the context of walking exercise should also be considered. With respect to reaching tasks for stroke patients, for instance, spatial manipulations might be used to increase maximum reaching distance, thereby enhancing motor recovery (Dean & Shepherd, 1997; Langhorne, Coupar, Pollock, 2009).

The results of our study beg the question what the limits of the perceptual illusions are. Our VR environment was stretched or compressed by a factor 1.2 relative to the previous session (cf. Cuperus et al., 2018); it has to be tested whether similar results are found with a stretch/compress factor 1.5, for instance. Also, it is important to study how many times the same factor can be applied in a row. We expected each manipulation to alter memory for the previous environment(s), but we do not know to what extent memory for the original environment remains intact. Even if previous memories are completely 'overwritten' by exposure to manipulated environments, there will still be limits in terms of realism; at some point, one will notice the manipulation because, for instance, an animal alongside the road became thrice as thick. Alternatively, if only the distance between objects in an environment is increased/decreased, this environment may become quite empty/

dense at some point. A possible solution to this issue might be to only manipulate the distance between the more obvious landmarks and to leave 'filler material' such as trees in place. The effectiveness of such alternatives should also be explored.

In conclusion, the results of our study for the first time showed that memory-related perceptual illusions can directly affect physical activity in humans. The effects we found are substantial; stretching previously experienced VR environments led participants to almost double their initial walking distance, whereas compressing the environments resulted in about half of the initial distance. These findings can be applied in the development of novel clinical applications.



CHAPTER 8

Summary and conclusions

Virtual reality (VR) is increasingly applied in healthcare; e.g., as a form of medical education, or to facilitate treatment or rehabilitation. However, there are still many untouched opportunities. The aim of this thesis was to better our understanding of how healthcare can benefit from VR by exploring two novel VR paradigms. Both these paradigms are based on the idea that feeling present in a VR environment can lead to highly realistic memories; i.e., a VR experience may be encoded into memory in a manner so similar to a physical world experience that it can even lead to difficulties remembering the source of stored information (Segovia & Bailenson, 2009). Part 1 of the thesis explored the utility of VR to simulate exposure to psychological trauma and subsequent trauma symptoms. This 'analogue model of psychological trauma' provides a novel method to study the basic mechanisms underlying trauma symptom development, and to create and test interventions. Part 2 investigated whether a 'memory-related perceptual illusion' can be used to affect physical activity. This paradigm is based on how we memorize spatial representations of our environment and may be useful in the field of rehabilitation. The main findings and conclusions of the thesis are described in the following sections.

Part 1: An analogue model of psychological trauma

A better understanding of the basic mechanisms underlying trauma symptom development can provide novel insight into how symptoms can be reduced. Clinical studies may be useful in this respect, but a limitation of such studies is that they often rely on retrospective reports of trauma-related reactions many years later. As argued by Candel and Merckelbach (2004), this is problematic because people in general, and patients with trauma symptoms in particular, find it difficult to give accurate descriptions of past emotional states. Moreover, reports of memory for traumatic events often change over time (Engelhard, van den Hout, & McNally, 2008), because individuals may interpret memories differently over time (Engelhard & McNally, 2015; see also Lommen, van der Schoot, & Engelhard, 2014). Experimental analogues are therefore warranted (James et al., 2016). A well-established analogue model of psychological trauma is the trauma film paradigm (TFP), which involves showing non-clinical participants unpleasant films under controlled laboratory settings (Horowitz, 1969; Lazarus, 1964). This elicits measurable responses analogous to symptoms experienced during and shortly after viewing a traumatic event in real life, such as increases in negative mood (Clark, Mackay, & Holmes, 2015) and intrusive memories of the film (Holmes & Bourne, 2008; James et al., 2016). However, watching films seems to be a somewhat passive endeavour that lacks active behavioural engagement (Dibbets & Schulte-Ostermann, 2015). VR may provide a better alternative. Like the

TFP, a benefit of VR over the use of autobiographical memories is that it allows for experimental control. Furthermore, VR can induce a greater sense of presence than watching a film on a two-dimensional screen and it allows interaction with the environment, which may lead to more realistic (Slater, 2009) and more emotional (Riva et al., 2007) responses to portrayed events; i.e., greater user effects.

The general objective of part 1 of this thesis was to validate the utility of a VR game as an experimental analogue of psychological trauma. In this game, participants had to navigate through an old mansion which is generally scary and contains several aversive events (e.g., a cabinet that suddenly falls over and a poltergeist that spawns nearby) that were triggered by their actions and decisions. The results of chapter 2 suggest that this VR paradigm may provide a useful method of inducing negative memories, because the memories induced by playing the game were strong enough to be affected by a dual-task intervention—recalling the most negative memory of the game while putting wooden figures into matching holes in a box (shape sorter) without visual feedback—but not by recall only; i.e., the dual-task intervention led to greater decreases in memory emotionality. This finding is in line with the working memory account of eye movement desensitization and reprocessing (EMDR). According to this theory, keeping a memory in mind and carrying out a dual-task both tax the limited capacity of working memory. As a result of this, the memory becomes less vivid and less emotional (Andrade, Kavanagh, & Baddeley, 1997; Gunter & Bodner, 2008; Smeets, Dijs, Pervan, Engelhard, & van den Hout, 2012), and is stored as such into long-term memory (van den Hout & Engelhard, 2012). It is unclear why the dual-task intervention did not lead to reductions in memory vividness, but it should be noted that several studies found effects just for emotionality (Andrade et al., 1997, experiment 2; Engelhard et al., 2010; Kavanagh, Freese, Andrade, & May, 2001; Schubert, Lee, & Drummond, 2011) or vividness (Andrade et al., 1997, experiment 1; van den Hout, Engelhard, Beetsma et al., 2011, experiment 2; van den Hout, Engelhard, Rijkeboer et al., 2011, experiment 4; Leer, Engelhard, & van Den Hout, 2014; Maxfield, Melnyk, & Hayman, 2008, experiment 1), and not for both.

The study described in chapter 2 was only a first step towards validating the utility of the VR paradigm; the question how the findings relate to the well-established TFP was left unanswered. Therefore, chapter 3 provided a direct comparison between both paradigms. The trauma film used in this comparison consisted of four scenes depicting acts of violence and rape. Clips from this movie induced intrusive memories in several studies (e.g., Schaich, Watkins, & Ehring, 2013; Verwoerd, de Jong, & Wessel, 2008). Furthermore, a variety of physiological measures (cortisol level, heart rate, and pupil dilation) confirmed successful stress induction for these scenes (Henckens, Hermans, Pu, Joëls, & Fernández, 2009), and a longer version of the rape scene elicited a higher heart rate, more distress, and more intrusive memories than three other trauma films (Weidmann, Conradi, Gröger, Fehm, & Fydrich, 2009). The results of the study indicated that the film and VR game were equally effective in inducing vivid and intrusive memories. This is noteworthy, because the content of the film is highly aversive (rated R) compared to the content of the VR game (rated PG-13). Watching the film did result in memories of higher emotional valence. However, as argued by James et al. (2016), in selecting a film, it is not necessarily the aim to find the most aversive film that an ethical committee will allow. They advised researchers to aim to find a film that is sufficiently aversive to model trauma. Thus, in light of ethical considerations and the presumably beneficial qualities of VR, using the VR game seems preferable.

Finally, chapter 4 presented a study in which the VR paradigm was used to test the effectiveness of an experimental VR-based trauma intervention that consists of a combination of elements from two other interventions: VR exposure therapy and EMDR. More specifically, the aim was to investigate whether a dual-task intervention in which the recall element is replaced by a VR exposure element can reduce memory vividness and emotionality too; i.e., instead of thinking of a memory, individuals look at an image in VR that represents a memory while carrying out the (non-visual) shape sorter task of chapter 2. If effective, this approach could be clinically useful when patients show signs of avoidance behaviour with respect to their traumatic memories during therapy. In those cases, (visual) retrieval cues might be particularly important for an intervention to take effect, because memories are only susceptible to updating when (re)activated (see Visser, Lau-Zhu, Henson, & Holmes, 2018). The VR paradigm made it possible to record three-dimensional screenshots of participants' VR experience while they played the game (from participants' point of view). After playing, participants viewed the images of the gameplay moments that they found the most unpleasant while they carried out the shape sorter task. In line with the working memory account of EMDR, both this experimental intervention and a more traditional recall variant outperformed a screenshot only control condition in terms of reductions in self-rated memory vividness and emotionality. Furthermore, it seems that both dual-task interventions had the same impact on vividness, but that the experimental screenshot version led to greater decreases in emotionality. Interestingly, visually supporting a negative memory does not seem to prevent the beneficial effects of dual-task processing on an emotional memory. Further investigation of the practical utility of this approach is warranted and the idea that it might especially be efficacious for highly avoidant individuals requires further testing.

Together, the three studies of part 1 provide a fruitful basis for the use of VR to study psychological trauma, and to create and test interventions. It seems worth exploring more complex and/or aversive VR games. However, from an ethical point of view, it can be considered a strength of the VR game used in this thesis that it is not extremely aversive; i.e., it may be aversive enough to model trauma. Investigation of the link between sense of presence and trauma symptoms would be another interesting direction for future research. This may be done by comparing a VR game with a two-dimensional version of the same game, for instance. Alternatively, a presence measure such as the ITC-Sense of Presence Inventory (Lessiter, Freeman, Keogh, & Davidoff, 2001) could be integrated in the design of the study described in chapter 3.

Part 2: Memory-related perceptual illusions

Perceptual illusions help us understand deficits in human perception, but they also have the potential to serve as treatment/rehabilitation methods. For instance, a mirror visual feedback technique was developed in the 1990s, in an attempt to alleviate phantom limb pain (Ramachandran & Rogers-Ramachandran, 1996; Ramachandran, Rogers-Ramachandran, & Cobb, 1995). It typically involves the use of a mirror across the patient's midline to create the illusion of having two complete limbs. Such 'false visual feedback' may provide relief of phantom limb pain, because of the brain's predilection for prioritizing visual feedback over somatosensory/proprioceptive feedback (Moseley, Gallace, & Spence, 2008). The technique has its limitations, however, because it relies on the presence of an unaffected limb and only allows for symmetric actions. A VR setup is not necessarily subject to such constraints and may thus provide a better alternative (for a review, see Dunn, Yeo, Moghaddampour, Chau & Humbert, 2017); seeing a virtual body from a first-person perspective can induce the illusion of ownership over (parts of) this virtual body (Slater, Spanlang, Sanchez-Vives, & Blanke, 2010). VR can be used to present the user with other types of false visual feedback as well, such as the manipulation of perceived orientation. In a technique called redirected walking, real-world rotations are transformed into increased or decreased rotations in the virtual environment. This allows users to walk through large-scale virtual environments while they physically remain in a small workspace; users can be redirected on a circular arc with a radius of at least 22 m while they believe that they are walking straight (Steinecke, Bruder, Jerald, Frenz, & Lappe, 2010). The same technique can also be used, for instance, to alter the onset of movement-evoked pain in people with neck pain (Harvie et al., 2015).

The main goal of part 2 of this thesis was to use a novel kind of perceptual illusion to influence users' physical activity. What the aforementioned false visual feedback examples have in common is that their effects are the direct result of a mismatch between visual feedback and somatosensory/proprioceptive feedback. The focus of this thesis was on a more indirect kind of perceptual illusion in VR that is 'mediated' by memory. In this paradigm, the user is presented with previously experienced, but modified environments and/or events; i.e., their spatial characteristics are altered, without notification to the user. It is based on the spatial memory framework proposed by Kosslyn (1987), who made a distinction between the representations of coordinate (metric) and categorical spatial relations (e.g., the side of an object in relation to another object). Typically, people are not very accurate in memorizing the precise metric properties of objects and their locations, especially after longer temporal delays. Thus, the manipulation of spatial distance in previously experienced environments and events may go unnoticed when the categorical information of these environments and events matches with memory. First, chapter 5 investigated whether this hypothesis is correct. In the study described here, participants took shots at a target on a soccer field and were shown three different types of VR replays of their performance on this task; one accurate representation of actual performance and two manipulated representations in which the distance between the ball and the target was adjusted. One manipulation made performance seem worse (miss distances multiplied by 1.5) and the other made performance seem better (miss distances multiplied by 0.5). The VR replays matched participants' memory in terms of the categorical spatial relations that were of main importance to the task; i.e., the side of the target along which the ball passed for each shot. As expected, all three were considered equally accurate representations of actual performance, indicating that the distance manipulations were not noticed. Furthermore, the type of replay manipulation positively correlated with feeling of competence but did not influence sports performance.

Next, chapter 6 tested whether manipulations of spatial distance in VR (i.e., memory-related perceptual illusions) can affect physical activity in a clinical population—patients with intermittent claudication—through a different approach. Intermittent claudication is a cramping pain or discomfort in the legs, which occurs during exercise, such as walking, and is relieved with rest (Lane, Ellis, Watson, & Leng, 2014). Current guidelines appoint supervised exercise therapy, consisting of treadmill or track walking to moderate claudication pain, as primary treatment for patients with intermittent claudication. A meta-analysis shows that this generally decreases patients' functional impairment, which is usually quantified as the distance that patients can walk before pain forces them to stop (Lane et al., 2014). In the study described in chapter 6, participants walked on a treadmill while moving through a VR environment three times and were instructed to walk until the pain forced them to stop before each session. All VR sessions contained the same environment, but in the second and third session it was 'stretched' and 'compressed' (or vice versa) in the direction of its walking trail (by 10% in comparison to the baseline environment). The categorical information in the subsequent sessions (i.e., landmarks and their order) matched that of the baseline VR session and these sessions also included a flag which marked the location of the previously reached walking distance (± 10%, depending on condition), thereby setting visual, attainable goals. None of the participants noticed the manipulations, while they did influence performance; participants walked furthest when interacting with the stretched environment.

The results of chapter 6 indicated great potential for the use of memory-related perceptual illusions to influence clinically relevant physical activity. However, patients with intermittent claudication typically have several comorbid conditions that may affect memory. Chapter 7 therefore assessed whether the findings of chapter 6 generalize to healthy individuals, so that inferences can be drawn with respect to conditions other than intermittent claudication as well. People normally do not easily reach a pain barrier while they walk on a treadmill, however, so the study described in chapter 7 used a task in which participants had to reproduce a baseline walking distance. This approach also made it possible to investigate whether the same manipulation can be applied multiple (three) times in a row (resulting in stretch/compress factors 1.2, 1.44, and 1.73 compared to baseline), with very short time intervals. Because false, suggestive information can lead to alterations in memory (Loftus, 2005), especially when conveyed through 'rich' forms of media such as VR (Segovia & Bailenson, 2009), each manipulation was expected to alter memory for the previous environment(s). In line with this prediction, participants in the stretched condition increased their walking distance each session, whereas participants in the compressed condition decreased their walking distance each session. Some participants did report having the idea that there (maybe) were differences in terms of time, speed, and/or distance between walking sessions. However, this group of participants did not perform differently from participants who did not notice anything at all, indicating that their categorical knowledge of the VR environment(s) overruled any suspicions. Moreover, the effects are substantial; stretching previously experienced VR environments led participants to almost double their initial walking distance, whereas compressing the environments resulted in about half of the initial distance. Step length was not influenced by the spatial manipulations, which indicates that the manipulations did not take effect on a basal motoric level.

The three studies of part 2 provide a framework for the use of memory-related perceptual illusions to affect physical activity in the context of rehabilitation. Future research should look into the further clinical utility of these illusions combined with walking. In patients with Parkinson's disease, for instance, treadmill training can improve gait (Mehrholz et al., 2015) and cognitive function (da Silva et al., 2018). Perhaps the use of the spatial manipulations of this thesis can further increase the effectiveness of treadmill exercise in this population. The utility of memory-related illusions outside the context of walking exercise should also be considered. With respect to reaching tasks for stroke patients, for instance, spatial manipulations might be used to increase maximum reaching distance, thereby enhancing motor recovery (Dean & Shepherd, 1997; Langhorne, Coupar, Pollock, 2009).

Future implications

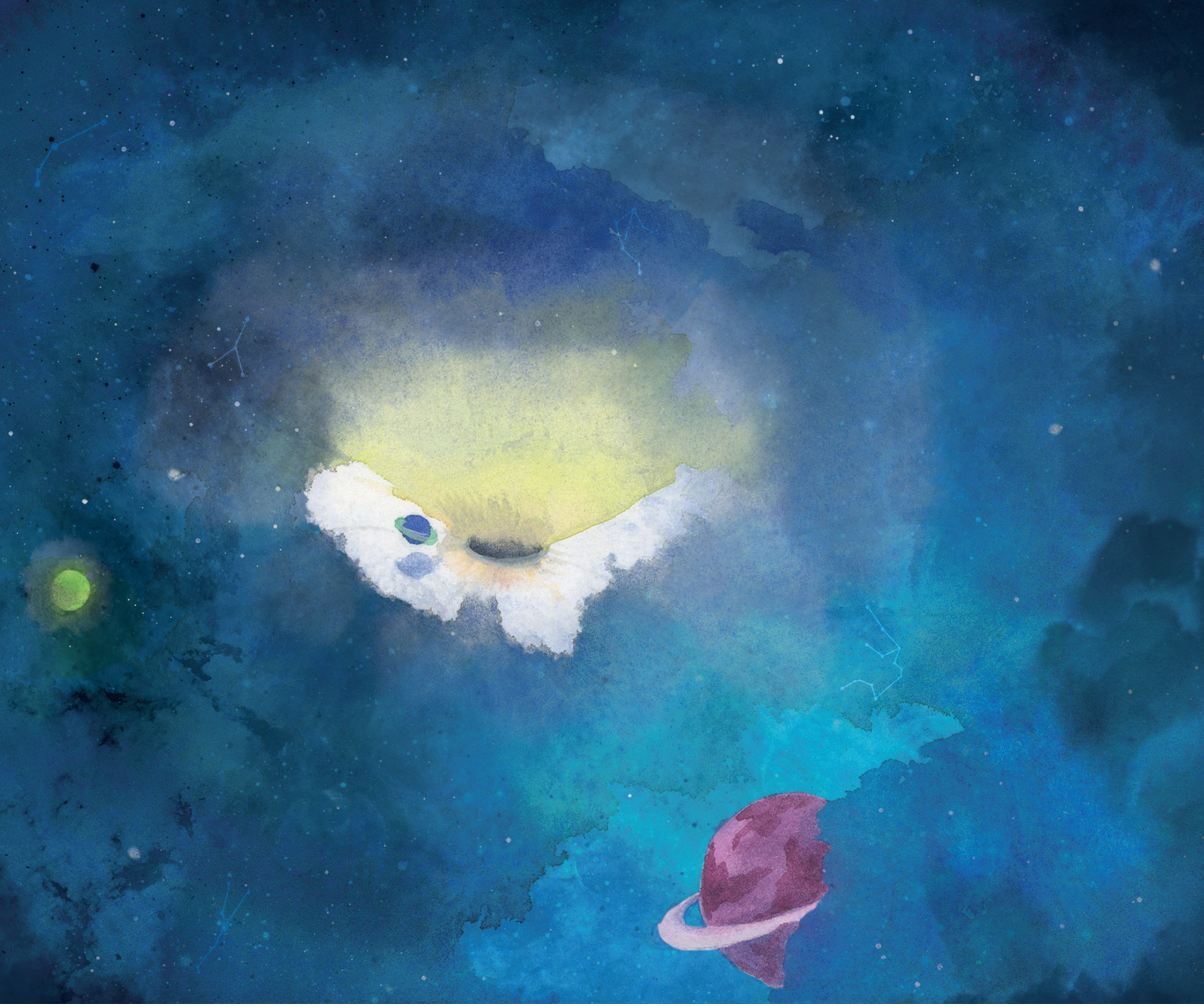
At present, the reasons to use VR in the field of healthcare often seem to be of practical nature. In case of VR exposure therapy, for instance, the main added value over real-life exposure seems to be that it allows exposure to all kinds of real-world situations (e.g., standing on top of a building or being surrounded by spiders) at a single location, thereby providing a cost- and time-efficient alternative. However, there is more to it when VR provides an important stepping stone towards confrontation with the real world; i.e., when an individual is too afraid to engage in exposure otherwise or when real danger is involved, such as in case of fear of driving. A similar observation applies to the use of VR medical simulators to support surgical training, especially in the context of riskier and/or rarer clinical scenarios. Furthermore, VR may be the most suitable medium in these cases, because it is thought to yield a strong resemblance between user responses to virtual stimuli/interactions and parallel responses to real-world counterparts (Cummings & Bailenson, 2016). This was also the main rationale behind the research of part 1 of this thesis; the TFP is an effective method to model psychological trauma, but the increased sense of presence that VR can provide implies that it has the potential to be a more effective research tool than watching a two-dimensional film.

The above examples show that VR can be of great value aside from potential cost- and time-related benefits. However, the most valuable feature of VR may be that it is not subject to the limitations of the physical world, which allows for a range of entirely novel paradigms. For instance, the transformation of real-world rotations into increased or decreased rotations in VR (Steinecke et al., 2010) and the illusion of ownership over a virtual body with manipulated body proportions (Kilteni, Normand, Sanchez-Vives, & Slater, 2012) are both 'VR-exclusive' methods that can be used to modulate pain (Harvie et al., 2015; Mancini, Longo, Kammers, Haggard, 2011). They are clear illustrations of the fact that VR allows elements of the user and his/her environment to be manipulated in ways that are difficult or even impossible to realize otherwise. This is demonstrated by the paradigm introduced in part 2 of this thesis as well; i.e., the manipulation of the spatial characteristics of previously experienced virtual environments and/or events as a means to affect physical activity.

Taken together, the work presented in this thesis stresses the relevance of establishing which manipulations VR allows for, testing their user effects, and exploring whether these manipulations can be of use in the field of healthcare. Such knowledge provides useful guidelines for the development of future VR applications.

Conclusions

VR is playing an important role, or has the potential to do so, in several aspects of healthcare. In this thesis, two novel VR-based paradigms were explored in an attempt to increase our understanding of how VR can be applied in healthcare. Part 1 provides a fruitful basis for the use of VR to study psychological trauma, and to create and test interventions. Part 2 provides a framework for the use of memory-related perceptual illusions to affect physical activity in the context of rehabilitation. Further research into the precise mechanisms underlying these paradigms is warranted, as well as further exploration of their utility. On a more general level, the work of this thesis may serve as inspiration for the development of other novel, innovative paradigms in the field of VR and healthcare.



APPENDIX

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Nederlandse samenvatting
Dankwoord
Curriculum Vitae
List of publications

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Nederlandse samenvatting

Virtual reality (VR) stelt de gebruiker in staat een virtuele, computer-gesimuleerde wereld te ervaren. Een VR-ervaring kan zo innemend zijn dat de gebruiker zich werkelijk aanwezig voelt in een gesimuleerde omgeving. Er wordt verondersteld dat dit gepaard gaat met realistische reacties op de omgeving en gebeurtenissen die daarin plaatsvinden (Cummings & Bailenson, 2016). Dit is niet alleen van grote waarde voor de entertainmentindustrie, maar kan ook nuttig zijn voor de gezondheidszorg. Zo heeft VR-exposuretherapie al sinds tenminste het midden van de jaren negentig mensen kunnen helpen om specifieke fobieën te overwinnen, zoals hoogtevrees of angst voor spinnen, omdat blootstelling aan gevreesde stimuli in VR echte fysiologische angstreacties kan oproepen (Rothbaum et al., 1995; voor meta-analyses, zie bijv. Morina, Ijntema, Meyerbröker, & Emmelkamp, 2015; Parsons & Rizzo, 2008). Een ander bekend voorbeeld van een zorgtoepassing is het gebruik van VR als methode om pijn te bestrijden, zoals de pijn die wordt ervaren tijdens wondzorg door patiënten met ernstige brandwonden (Hoffman et al., 2008; Hoffman Patterson, Carrougher, & Sharar, 2001). De heersende opvatting is dat VR in staat is pijn te verminderen door middel van afleiding (Garrett et al., 2014); een VR-ervaring kan zo prikkelend zijn dat er weinig aandacht overblijft voor de verwerking van pijnsignalen (Hoffman et al., 2001).

Er is al een breed scala aan VR-zorgtoepassingen beschikbaar, maar er is nog veel onontgonnen terrein. Het doel van dit proefschrift is om ons inzicht in hoe VR kan worden toegepast in de gezondheidszorg te vergroten door twee nieuwe VR-paradigma's te verkennen. Beide zijn gebaseerd op het idee dat VR-ervaringen zo werkelijk kunnen lijken dat ze op een later moment zelfs foutief als ervaringen uit de fysieke wereld kunnen worden herinnerd (Segovia & Bailenson, 2009). Deel 1 van het proefschrift gaat over de bruikbaarheid van VR om blootstelling aan psychotrauma te simuleren. Dit 'analoge model van psychotrauma' kan worden gebruikt om de basismechanismen te bestuderen die ten grondslag liggen aan de ontwikkeling van traumasymptomen, en om interventies te ontwikkelen en te testen. Deel 2 heeft als onderwerp de bruikbaarheid van 'geheugengerelateerde perceptuele illusies' ter beïnvloeding van fysieke activiteit. Dit paradigma is gebaseerd op hoe we ruimtelijke representaties van onze omgeving onthouden en kan nuttig zijn op het gebied van revalidatie.

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Deel 1: Een analoog model van psychotrauma

Een beter begrip van de basismechanismen die ten grondslag liggen aan de ontwikkeling van traumasymptomen kan helpen nieuw inzicht te verschaffen in hoe deze symptomen kunnen worden bestreden. Klinische studies kunnen een nuttig bijdrage leveren in dit opzicht, maar een beperking van zulke studies is dat ze vaak afhankelijk zijn van beschrijvingen van trauma-gerelateerde reacties uit het verleden. Wat dit problematisch maakt is dat mensen het moeilijk vinden om hun vroegere emotionele staten accuraat te beschrijven (Candel & Merckelbach, 2004). Bovendien veranderen beschrijvingen van traumatische gebeurtenissen vaak in de loop der tijd (Engelhard, van den Hout, & McNally, 2008), omdat herinneringen over tijd anders geïnterpreteerd kunnen worden (Engelhard & McNally, 2015; zie ook Lommen, van der Schoot, Engelhard, & 2014). Het is daarom van belang dat er ook experimenteel psychopathologisch onderzoek plaatsvindt (James, 2016). Het traumafilmparadigma is een gevestigd analoog model van psychotrauma waarbij aan niet-klinische participanten aversieve films worden getoond onder gecontroleerde laboratoriumomstandigheden (Horowitz, 1969; Lazarus, 1964). Dit levert meetbare reacties op die overeenkomen met symptomen die worden ervaren tijdens en kort na het bekijken van een traumatische gebeurtenis in het echte leven, zoals een toename in negatieve stemming (Clark, Mackay, & Holmes, 2015) en intrusieve herinneringen aan de film (Holmes & Bourne, 2008; James et al., 2016). Films kijken lijkt echter een wat passieve handeling te zijn waarbij gedragsmatige betrokkenheid ontbreekt (Dibbets & Schulte-Ostermann, 2015). VR kan een beter alternatief bieden. Net als het traumafilmparadigma is een voordeel van VR ten opzichte van het gebruik van autobiografische herinneringen dat het experimentele controle toelaat. Bovendien kan VR een sterker gevoel van aanwezigheid opwekken dan het kijken van een film en maakt het interactie met de omgeving mogelijk, wat kan leiden tot realistischere (Slater, 2009) en emotionelere (Riva et al., 2007) reacties.

Deel 1 van dit proefschrift is gericht op de validatie van het gebruik van een VR-game als experimenteel analoog van psychotrauma. In deze game navigeerden participanten door een oud huis met verschillende aversieve gebeurtenissen, zoals een kast die zomaar omvalt en een geest die plotseling verschijnt. De resultaten van hoofdstuk 2 suggereren dat deze methode tot sterke negatieve herinneringen kan leiden. Deze conclusie is gebaseerd op de bevinding dat herinneringen die werden opgewekt door het spel te spelen sterk genoeg waren om te worden beïnvloed door een dubbeltaakinterventie (de meest negatieve herinnering aan het spel vasthouden in het geheugen en ondertussen een dubbeltaak uitvoeren), maar niet door alleen het vasthouden van de herinnering; de dubbeltaakinterventie leidde tot grotere afnames van emotionaliteit. Deze bevinding sluit aan bij de werkgeheugenverklaring van eye movement desensitization and reprocessing (EMDR). Volgens deze theorie belasten het vasthouden van een herinnering en het uitvoeren van een dubbeltaak beide de beperkte capaciteit van het werkgeheugen, met als gevolg dat de herinnering minder levendig en minder emotioneel wordt (Andrade, Kavanagh, & Baddeley, 1997; Gunter & Bodner, 2008; Smeets, Dijs, Pervan, Engelhard, & van den Hout, 2012) en als zodanig opgeslagen in het langetermijngeheugen (van den Hout & Engelhard, 2012).

In hoofdstuk 3 is het VR-paradigma vervolgens direct vergeleken met het traumafilmparadigma. De traumafilm die in deze vergelijking werd gebruikt bestond uit vier scènes van een film met geweld en verkrachting. Clips uit deze film veroorzaakten intrusieve herinneringen in verschillende onderzoeken (bijv. Schaich, Watkins, & Ehring, 2013; Verwoerd, de Jong, & Wessel, 2008). Ook bevestigden verschillende fysiologische metingen (cortisolniveau, hartslag en pupilverwijding) succesvolle stressinductie voor deze scènes (Henckens, Hermans, Pu, Joëls, & Fernández, 2009) en een langere versie van de verkrachtingsscène resulteerde in een hogere hartslag, meer distress en meer intrusieve herinneringen dan drie andere traumafilms (Weidmann, Conradi, Gröger, Fehm, & Fydrich, 2009). De resultaten van de studie suggereerden dat de film en VR-game leidden tot ongeveer even levendige en intrusieve herinneringen, terwijl de inhoud van de film veel aversiever is dan die van de VR-game.

Ten slotte is het VR-paradigma in hoofdstuk 4 gebruikt om de effectiviteit van een experimentele VR-gebaseerde trauma-interventie te testen die bestaat uit een combinatie van elementen uit twee andere interventies: VR-exposuretherapie en EMDR. Meer specifiek was het de bedoeling om te onderzoeken of er ook sprake is van reducties in levendigheid en emotionaliteit van een negatieve herinnering wanneer naar een VR-beeld wordt gekeken dat deze herinnering representeert (in plaats van het vasthouden van de herinnering) terwijl een dubbeltaak wordt uitgevoerd. In overeenstemming met de werkgeheugenverklaring van EMDR presteerden zowel deze experimentele variant waarin het geheugen visueel wordt ondersteund als een meer traditionele herinneringsvariant beter dan een controleconditie waarin zonder dubbeltaak werd gekeken naar een VR-beeld. Visuele ondersteuning van een negatieve herinnering lijkt dus geen belemmering te vormen voor de positieve effecten van dubbeltaakverwerking.

De drie studies van deel 1 vormen samen een vruchtbare basis voor het gebruik van VR om psychotrauma te bestuderen, en om interventies te ontwikkelen en testen. Een interessante richting voor toekomstig onderzoek is het verband tussen gevoel van aanwezigheid en traumasymptomen. Daarnaast lijkt het de moeite waard om de bruikbaarheid van meer complexe en/of aversieve VR-games te verkennen. Echter, vanuit een ethisch oogpunt kan het als een voordeel worden beschouwd wanneer een VR-game niet extreem aversief is maar wel net aversief genoeg in het licht van bovengenoemde doeleinden.

Deel 2: Geheugengerelateerde perceptuele illusies

Perceptuele illusies helpen ons tekortkomingen in de menselijke perceptie te begrijpen, maar ze kunnen ook dienen als behandelings- en revalidatiemethoden. Zo is in de jaren negentig een visuele spiegelfeedbacktechniek ontwikkeld met als doel om fantoompijn te verlichten (Ramachandran & Rogers-Ramachandran, 1996; Ramachandran, Rogers-Ramachandran, & Cobb, 1995). Deze techniek bestaat typisch uit de plaatsing van een spiegel over de middellijn van de patiënt om de illusie van twee volledige ledematen te creëren. Dergelijke 'valse visuele feedback' kan verlichting van fantoompijn bieden vanwege de prioritering van visuele feedback over somatosensorische/proprioceptieve feedback door de hersenen (Moseley, Gallace en Spence, 2008). De techniek heeft echter zijn beperkingen, omdat hij afhankelijk is van de aanwezigheid van een niet-aangedane ledemaat en alleen symmetrische acties toestaat. Een VR-opstelling is niet gebonden aan dergelijke restricties en kan daarom een beter alternatief bieden (voor een review, zie Dunn, Yeo, Moghaddampour, Chau & Humbert, 2017); het zien van een virtueel lichaam vanuit een eerstepersoonsperspectief kan de illusie van eigenaarschap over (delen van) dit virtuele lichaam creëren (Slater, Spanlang, Sanchez-Vives, & Blanke, 2010). VR kan ook worden gebruikt om de gebruiker andere soorten valse visuele feedback te geven, zoals de manipulatie van waargenomen oriëntatie. Rotaties in de fysieke wereld kunnen bijvoorbeeld worden omgezet in vergrote of verkleinde rotaties in VR. Hierdoor kunnen gebruikers door grootschalige virtuele omgevingen lopen terwijl ze in werkelijkheid in een kleine ruimte blijven; gebruikers kunnen worden omgeleid over een cirkel met een straal van ten minste 22 meter, terwijl ze geloven dat ze rechtdoor lopen (Steinecke, Bruder, Jerald, Frenz, & Lappe, 2010). Dezelfde techniek kan bijvoorbeeld ook worden gebruikt om pijn ontstaan door nekbeweging te beïnvloeden (Harvie et al., 2015).

Deel 2 van dit proefschrift gaat over het gebruik van een nieuw type perceptuele illusie om de fysieke activiteit van de gebruiker te beïnvloeden. Wat de bovengenoemde voorbeelden van valse visuele feedback gemeen hebben is dat de effecten ervan het directe resultaat zijn van een mismatch tussen visuele feedback en somatosensorische/proprioceptieve feedback. Het VR-paradigma van deel 2 betreft een meer indirect type perceptuele illusie dat 'gemedieerd' wordt door het geheugen. De gebruiker wordt blootgesteld aan eerder ervaren, maar ruimtelijk gemodificeerde omgevingen en/of gebeurtenissen, zonder kennisgeving over de modificaties. Het is gebaseerd op een theorie van Kosslyn (1987), waarin een onderscheid wordt gemaakt tussen de representaties van metrische en categorische ruimtelijke relaties (bijv. de zijde van een object in relatie tot een ander object). Mensen zijn doorgaans niet erg goed in het onthouden van de exacte metrische eigenschappen van objecten en hun locaties, vooral na langere tijd. Wanneer de categorische informatie van eerder ervaren omgevingen en gebeurtenissen overeenkomt met het geheugen kan de manipulatie van ruimtelijke afstand hierin dus onopgemerkt blijven. In hoofdstuk 5 is eerst onderzocht of deze hypothese correct is. Participanten in de hier beschreven studie waren allen voetbalspelers die een aantal keer op een doelwit schoten, waarna ze drie verschillende soorten VR-replays bekeken van hun prestaties op deze taak (vanuit een eerstepersoonsperspectief); een waarin de prestatie accuraat werd weergegeven, een die de prestatie er beter uit liet zien door verkleining van de afstanden tussen de bal en het doelwit, en een die de prestatie er slechter uit liet zien door vergroting van deze afstanden. Zodoende werden alleen metrische eigenschappen gemanipuleerd, terwijl de relevante categorische informatie (de zijde van het target in relatie tot de bal in de gevallen waarin werd misgeschoten) niet werd aangepast. De resultaten van de studie suggereren dat deze manipulaties niet werden opgemerkt.

Vervolgens is in hoofdstuk 6 onderzocht of een specifieke klinische populatie kan worden geholpen door toepassing van dit soort manipulaties; patiënten met claudicatio intermittens. Deze patiënten ervaren een krampachtige pijn in de beenspieren die optreedt tijdens inspanning en met rust weer verdwijnt (Lane, Ellis, Watson, & Leng, 2014). Middels looptraining kan de afstand die gelopen kan worden voordat de pijn intreedt vergroot worden. In de studie van hoofdstuk 6 liepen participanten drie keer op een loopband terwijl ze door een bosachtige VR-omgeving bewogen, met de instructie om te lopen totdat de pijn ze noodzaakte te stoppen. Deze omgeving was telkens hetzelfde, maar werd na de eerste sessie een keer 'opgerekt' en een keer 'gecomprimeerd'. De categorische informatie (oriëntatiepunten en hun volgorde) bleef zodoende intact, maar werd later of eerder gepresenteerd dan tijdens de voorgaande sessie. Geen van de participanten merkte de manipulaties op, terwijl deze wel de prestaties leken te beïnvloeden; participanten liepen het verst wanneer ze interacteerden met de opgerekte omgeving.

De resultaten van hoofdstuk 6 wezen op veel potentie voor het gebruik van geheugengerelateerde perceptuele illusies om klinisch relevante fysieke activiteit te beïnvloeden. Echter, patiënten met claudicatio intermittens hebben veelal verschillende comorbide aandoeningen die van invloed kunnen zijn op het geheugen. Hoofdstuk 7 onderzocht daarom of de bevindingen generaliseren naar gezonde individuen. Mensen bereiken normaal gesproken echter niet snel een pijngrens terwijl ze op een loopband lopen, dus er werd gebruik gemaakt van een taak waarbij participanten een aantal keer een loopafstand dienden te reproduceren. Deze aanpak maakte het ook mogelijk om te onderzoeken of dezelfde manipulatie meerdere (drie) keer achter elkaar kan worden toegepast, met zeer korte tijdsintervallen. Het telkens oprekken van de vorige VR-omgeving leidde ertoe dat participanten hun aanvankelijke loopafstand bijna verdubbelden, terwijl het telkens verder inkrimpen ervan resulteerde in bijna de helft van de initiële loopafstand.

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De drie studies van deel 2 bieden een kader voor het gebruik van geheugengerelateerde perceptuele illusies om fysieke activiteit te beïnvloeden in de context van revalidatie. Er is onderzoek nodig naar de verdere klinische bruikbaarheid van deze illusies. Bij patiënten met de ziekte van Parkinson kan looptraining bijvoorbeeld het looppatroon (Mehrholz et al., 2015) en cognitieve functies verbeteren (da Silva et al., 2018). Mogelijk kan het gebruik van de ruimtelijke manipulaties van dit proefschrift de effectiviteit van loopoefeningen in deze populatie verder vergroten. Het nut van geheugengerelateerde illusies buiten de context van loopoefeningen moet ook worden overwogen.

Conclusies

In dit proefschrift zijn twee nieuwe VR-paradigma's verkend met als doel om ons inzicht in hoe VR kan worden toegepast in de gezondheidszorg te vergroten. Deel 1 biedt een vruchtbare basis voor het gebruik van VR om psychotrauma te bestuderen, en om interventies te ontwikkelen en testen. Deel 2 biedt een kader voor het gebruik van geheugengerelateerde perceptuele illusies om fysieke activiteit te beïnvloeden in de context van revalidatie. Verder onderzoek naar de precieze mechanismen die ten grondslag liggen aan deze paradigma's is nodig, evenals verdere verkenning van de bruikbaarheid ervan. Op een meer algemeen niveau kan dit proefschrift dienen als inspiratie voor de ontwikkeling van andere nieuwe, innovatieve VR-paradigma's. Het is belangrijk om vast te stellen wat VR mogelijk maakt, de bijbehorende gebruikerseffecten te testen en te onderzoeken of deze manipulaties van nut kunnen zijn voor de gezondheidszorg. Zulke kennis biedt nuttige richtlijnen voor de ontwikkeling van toekomstige VR-toepassingen.

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Curriculum Vitae

Anne Cuperus was born on January 26, 1987 in Ede, the Netherlands. He finished his pre-university education at CSG Het Streek in 2005. At Utrecht University, he then obtained a bachelor's degree in Law (2010), a master's degree in Dutch Private Law (2011), a bachelor's degree in Psychology (2013), and a master's degree in Neuropsychology (2015). Anne always had a keen interest in IT, which is reflected in the subject of each thesis he wrote. During the Master Neuropsychology he followed an internship at the IT company Triple. He continued to work there after finishing his study and co-founded a project in which novel methods of applying technology in the field of healthcare were explored. While working at Triple, he became an external PhD candidate at Leiden University in 2016. Anne noticed that his research triggered a growing interest in the clinical practice of psychology. Since 2018, he works as a psychologist at HSK Groep (Utrecht, the Netherlands).

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